DECREASING VARIATION IN COOK COLOR OF GROUND BEEF PATTIES VARYING IN MYOGLOBIN AND pH USING ACETIC ACID AND HYDROCOLLOID SOLUTIONS

A Thesis

by

TERESA LYNN ALDREDGE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2009

Major Subject: Food Science and Technology

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Approved by:

Chair of Committee,	Rhonda K. Miller
Committee Members,	Jimmy T. Keeton
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ABSTRACT

Decreasing Variation in Cook Color of Ground Beef Patties Varying in Myoglobin and pH Using Acetic Acid and Hydrocolloid Solutions. (December 2009)

Teresa Lynn Aldredge, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Rhonda K. Miller

The objective was to examine the use of acetic acid (AA) with xanthan gum (XG) or konjac flour (KF) to reduce variation in cooked color of ground beef patties varying in myoglobin and pH. Beef clods were selected from carcasses of young (<24 months, Y) and mature (>48 months, M) animals. Within each age category, high (>6.0, H) and normal pH (5.3-5.7, N) clods were chosen. Ground beef was prepared from each maturity/pH combination and treatments applied at 12% of the meat block: control (mixed only), 0.5% AA, 0.25% XG/0.5% AA, or 0.125% KF/0.5% AA. Dry and moist cooking was performed in a convection oven to internal temperatures: 65.6°C, 71.1°C, and 76.7°C. Patties were held at 76.7°C for up to 240 min in dry and moist environments. Internal (assessed at 0, 120, and 240 min of holding) and external (assessed every 30 min, 0 to 240 min of holding) color evaluations (CIE L*a*b*, visual doneness, and pink scores) were conducted. Three replications were performed. The YN patties had the most done appearance internally and the highest denatured myoglobin percentage. Generally, the YH and MN patties had responses between YN and MH got most variables. The MH patties had the highest internal a* color space

values, lowest degree of doneness scores and low percentage of denatured myoglobin. The YN patties responded normally to the different internal temperatures achieved during cooking. The YH, MN, and MH patties had increased doneness to 71.1°C and plateaued between 71.1°C to 76.7°C. Visual degree of doneness decreased during moist holding and this was most evident in dry cook/moist held patties. Patties from MH meat were not affected by the treatments as much as the other meat types. The inclusion of AA, XG/AA, and KF/AA in patties made from YH and MN can effectively reduce visible redness and increase myoglobin denaturation in comparison to the control YN beef patties. These ingredients could be viable options to reduce the variation that pH or myoglobin content imparts on ground beef patty cooked color, but as seen in the MH meat, treatment additions were not effective for overcoming both pH and high myoglobin content.

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CHAPTER I

INTRODUCTION

Persistent pink color in cooked ground beef has been associated with undercooked beef by consumers and foodservice workers, even when the product has been sufficiently heat processed to meet the required temperature endpoint for safety. High pH beef has been hypothesized to contribute to persistent pink color development, because myoglobin does not denature at the same rate during heating (Mendenhall 1989; Trout 1989; van Laack and others 1996b; Lytras and others 1999). It is hypothesized that the addition of an acetic acid and hydrocolloid combination system will decrease meat pH levels, which in turn will help reduce persistent pinking. Persistent pinking may also be affected by the concentration amounts of myoglobin in muscle tissue. Meat from mature animals has a higher level of myoglobin than beef from young animals (Kinsman and others 1994). Therefore, the objective of this study was to examine the effects of an organic acid and two acidic/hydrocolloid systems, different cooking and holding methods (dry vs. moist), holding times, and internal endpoint cook temperatures of ground beef that differs in pH and myoglobin content on internal and external cooked color.

This thesis follows the style of Journal of Food Science.

CHAPTER II

LITERATURE REVIEW

The goal of the beef industry is to produce quality beef products to ensure consumer satisfaction; however some inherent physiological conditions may give an undercooked appearance. Meat color, both raw and cooked, can be an indicator of quality and safety to consumers and is dependent on pH, meat source (an animal's age, sex, species, feeding regimen, and pre-harvest handling conditions), packaging, freezing state, fat content, added ingredients, and the oxidantion/physical state of myoglobin (King and Whyte 2006). It is known that color does not indicate degree of doneness and the only way to effectively determine if meat has been fully cooked is to use a meat thermometer (Hague and others 1994; Lavelle and others 1995; van Laack and others 1996b; Berry and Bigner-George 1999). The USDA-Food Safety Inspection Service (FSIS) has been urging consumers to use thermometers, not visual assessment of degree of doneness for the last 10 years (FSIS 1998; FSIS 2003).

Two problems have been observed in ground beef patties that could have safety and quality ramifications: premature browning and persistent pink color. Premature browning is when the ground beef has not been properly thermally processed but has turned brown, indicating well-done ground beef (Hague and others 1994; Warren and others 1996). Persistent pink color results in cooked products that are fully thermally processed but still retain their pink or red color (Mendenhall 1989; Trout 1989; Berry 1994). Rejecting or accepting patties on cooked color alone for safety is not wise. It may eliminate some properly cooked patties, result in patties with diminished sensory qualities, or produce patties that are not fully cooked that may play a part in food-borne illness.

Meat Type

Final pH postmortem impacts meat color and is the main beef quality defect present when pH is higher (>6.0) than normal (5.6-5.8). This condition is defined as dark, firm, and dry (DFD) beef where the pH of meat does not drop post-harvest and the resultant beef is darker and retains more moisture than normal beef (Aberle and others 2001). Myofibrillar proteins tightly bind water so light does not scatter on the surface of DFD meat as much as normal pH meat thus causing of the darkness and dry appearance (Seideman and others 1984). During cooking myoglobin does not denature at the same rate in high pH meat when compared to meat with a normal pH (Hunt and others 1999; Mendenhall 1989; Trout 1989). Additionally at higher pH, the heat stability of myoglobin is higher.

Myoglobin denaturation is important in meat products as myoglobin denaturation is a visual indicator of the level of doneness and safety to consumers. Myoglobin denaturation is dependent on the ligand, redox state of the iron, pH, degree of heating, and the stability of the protein. Heating causes denaturation of the myoglobin protein to occur, but the rate and extent of denaturation will vary based on the aforementioned attributes. Though it would be advantageous to segregate acceptable and unacceptable beef on pH alone, there are other factors that contribute to color change when ground beef patties are heated. One study reported that cooked patties that were red in appearance were usually from patties high in pH, but high pH did not always produce red patties (van Laack and others 1996b), even though pH is one of the main contributors to cooked color development in ground beef patties (Mancini and others 2005).

Research has examined the relationship between meat pH and myoglobin denaturation or visual degree of doneness. Hunt and others (1999) reported that patties of normal pH where myoglobin was primarily in the deoxymyoglobin state still had a red appearance when heated to 55 °C and 65 °C; whereas patties in the metmyoglobin and oxymyoglobin pigment states appeared fully cooked at 55 °C and higher. Ryan and others (2006) provided similar data and also showed an increase in myoglobin denaturation when oxymyoglobin was the primary myoglobin state. When patties were freshly ground or made from the surface meat in a retail over-wrap package, where oxymyoglobin would be the primary state of the pigment, patties also tended to be browner in appearance when cooked (Killinger and others 2000). "Hard-to-cook" ground beef patties typically have the highest pigment concentrations (van Laack and others 1996b). Dark cutting beef has been shown to have more myoglobin than normal meat (Moiseev and Cornforth 1999). It can only be assumed that these two categories overlap someway. Color changes that indicate pinking are typically measured on the interior of cooked ground beef patties since external color of cooked patties shows no pinking and minimal raw color (Moiseev and Cornforth 1999).

Animal age affects meat color. More mature beef animals, such as cows and bulls, tend to have a higher percentage of carcasses that are rated dark cutting (2.1%) (Hale and others 2007) compared to 0.37% reported for all beef carcasses (Smith and others 2005). Dark cutting meat is discounted by packers and is usually sent to ground beef applications or to other pre-cooked products, as it does not have retail case appeal to consumers. Meat from mature animals also has higher concentrations of myoglobin thus it appears darker than normal beef. High myoglobin content and the DFD condition makes meat are more susceptible to persistent pink color.

Cooking and Holding

Many studies have compared cooking methods such as pan-frying, broiling, roasting, microwaving, grilling, and convection oven cooking to monitor their effect on ground beef patty attributes. Foodservice establishments utilize both moist and dry cooking methods to induce a specific visual quality, product yield, and flavor in ground beef patties. Holding ground beef patties under both dry and moist conditions is also practiced in the food service industry. In food service, it is common for foods to be held so that most preparation occurs during non-peak times. According to the 2005 Food Code (HHS 2005), meat products do not have a maximum time that they can be held hot, but the meat must remain >57°C. Loss in quality is typically an issue in meat products that are held for long periods of time. Meat color can be affected by cooking environment, as well as holding temperature. Persistent pink color has been observed in cooked ground beef patties, in which the pink or red color does not disappear when patties are fully cooked, even at well-done temperatures (Berry and Bigner-George 1999). Pink color can also develop during holding of patties that had presented no evidence of pink color post-cooking. Short-term holding after cooking has been shown to reduce the pink color (Berry and Bigner-George 2000; Ryan and others 2006). Holding for up to 90 min past cooking has been shown to decrease yield and increase doneness scores (Berry and Liu 1998); however, information of the effects of long-term hot holding on meat color, specifically redness, are not available, nor are data comparing these two cooking and holding methods. In low-fat ground beef patties (10% fat), the meat source and ingredients have a greater affect on cooking characterizes than the cooking methods used to cook those patties (Berry 1997).

Internal Cook Temperature

Generally, cooking to a lower internal temperature results in redder, softer patties with less visual doneness, whereas cooking to a higher internal temperature results in a firmer patties with browner cooked color (Liu and Berry 1996; Hunt and others 1999; Lyon and others 2000). Monitoring internal temperature of ground beef patties is the only sure way to determine doneness (Warren and others 1996). The pink color that remains in ground beef patties is probably due to incomplete denaturation of myoglobin at temperatures <76°C or the development of a stable pink hemochrome at temperature >76°C (Trout 1989).

Acetic Acid Use in Meat Products

The use of different acids including lactic, citric, and acetic and their salts have been and are currently being used in meat products. In most cases, acids are used as antimicrobials, flavor enhancers, and raw meat color stabilizers (Maca and others 1997; Phillips and others 2001; Stivarius and others 2002; Seyfert and others 2007). Even a small decrease in meat pH (0.1-0.2 points) is sufficient to reduce pinking in pork chops (Mancini and others 2005) and acetic acid has been effectively used previously to reduce meat pH (Rao and Gault 1990). This study will look at small reductions in pH with the use of acetic acid to alter myoglobin color. One color attribute that has been reported to increase is a* color space values of ground beef patties cooked to 60 and 68°C. But no difference in a* color space values were noted when patties containing erythorbic acid were cooked to 71 or 77°C (Phillips and others 2001). A decrease in a* color space values was also seen with the addition of a lactic/acetic acid combination spray on strip steaks (Mikel and others 1996).

Acetic acid has been applied to meat products primarily in the form of marinades. Acid penetration is limited in these products, thus the effects are limited to the surface of these products. The most effective pickup of solutions was when the pH was between 4.0 and 5.0 (Rao and Gault 1990), and with longer marination time in steaks, greater effects on color were reported (Wenham and Locker 1976). Therefore, mixing the acid into a comminuted product should give a greater effect on cooked color development or color change than just soaking the product in a solution containing acetic acid (Seuss and Martin 1993).

Hydrocolloid Use in Meat Products

Hydrocolloids have been used in meat products to modify characteristics, primarily as texture modifiers and as fat replacers in comminuted meat products (Elliott and Green 1972; Foegeding and Ramsey 1986; Foegeding and Ramsey 1987; Trius and others 1994; Lin and Keeton 1998b; Huang and Lin 2004; Osburn and Keeton 2004). These non-meat ingredients have not been used to reduce color problems in cooked ground beef patties. Xanthan gum is stable over a range of pH and temperatures (CP Kelco 2008) and konjac flour is stable at acidic pH ranges and forms heat set gels (FMC BioPolymer 2008). When used in combination with an acetic acid solution, these hydrocolloids could reduce the pH of meat products. Hydrocolloids containing acid solutions may coat the meat proteins (Booren 2008), thus keeping the acid in contact with the proteins and allowing for a drop in meat pH.

Because many studies have looked at hydrocolloids as fat replacers, their effect on cook loss has been reported extensively. The use of all types of hydrocolloids, including, carrageenan, xanthan gum, konjac flour, and locust gum, has improved cooking yield in many differed comminuted meat products compared to control samples (Brewer and others 1992; Hsia and others 1992; Bullock and others 1995; Chin and others 1998; Lin and Keeton 1998a). Fox and others (1983) reported that the use of xanthan gum in vinegar (5% acetic acid) pickled frankfurters protected against cooking loss.

When acetic acid was used in marinades, there was an increase in the pH of the marinade with an equilibration of the pH between the marinating solution and the meat proteins (Rao and Gault 1990; Seuss and Martin 1993). To be effective, treatment solutions must reduce buffering capacity of the meat protein system which may make myoglobin more susceptible to denaturation. The use of acetic acid with hydrocolloids will be evaluated for this purpose.

Many factors play a role in the cooked color development of ground beef patties. Evaluation of ground beef patties in environments such as food service where color changes often occur would be the best way to evaluate the combined affect of different factors contributing to myoglobin color. Using a meat source that commonly gets discounted to low-end food service, including DFD and mature animal sources, could also help explain why cooked color differences appear during the cooking and holding processes. These evaluations of cooking and holding patties should increase our understanding of the conditions causing under-cooked appearance of ground beef patties. Understanding of the contributors is only the first step. This study will also test treatments that attempt to decrease differences in cooked color of ground beef patties induced by cooking, holding, and meat sources with hydrocolloids and acetic acid: a new application of ingredients currently used in comminuted meat products.

CHAPTER III

MATERIALS AND METHODS

Meat Selection

Beef shoulder clods, IMPS #114, (NAMP 1997) were obtained from four types of beef: normal pH (5.3 to 5.7) young (USDA A carcass maturity) beef carcasses, high pH (> 6.0) young (USDA A carcass maturity) beef carcasses, normal pH (5.3 to 5.7) mature (USDA C, D, and E carcass maturity) carcasses, and high pH (> 6.0) mature (USDA C, D, and E carcass maturity) carcasses. Both clods from the right and left sides of the carcasses were taken (n=6 for young animals; n=12 for mature carcasses) at >48 hours postharvest. Clods were transported to the Texas A&M University Rosenthal Meat Science and Technology Center and frozen until processed. Clods were randomly assigned to one of three replications (two animals represented per day for young animals and four for mature animals) and defrosted for 48 hours prior to processing day.

Treatment Preparation

Treatments were selected based on previous studies for their ability to reduce pH and color in high pH and high myoglobin (mature animals) meats (Booren 2008). Muscle tissue has good buffering capacity so it is difficult to find treatments that will effectively reduce the pH of the combined systems. Preliminary tests determined that addition of xanthan gum (Keltrol® 521; CP Kelco; Atlanta, Ga., U.S.A.) and konjac flour (Nutricol® XP 3464; FMC Biopolymer; Philadelphia, Pa., U.S.A) in combination with acetic acid would likely be the most effective treatments to reduce the pH and decrease dark color in beef steaks and roasts. Levels of ingredients in treatment solutions shown to be effective at low concentrations were selected for this study.

Three treatment solutions [0.5% acetic acid (AA), 0.25% xanthan gum + 0.5% acetic acid (XG/AA), or 0.125% konjac flour + 0.5% acetic acid (KF/AA)] were prepared prior to processing. The 0.5% (v/v) acetic acid treatment was prepared by adding acetic acid to double distilled deionized water (ddH_2O). For the treatments that include hydrocolloids, the 0.25% (w/v) of xanthan gum or 0.125% (w/v) of konjac flour was hydrated and solublized in ddH_2O. Once the specific hydrocolloid was solublized, 0.5% (v/v) acetic acid was added and the solution brought to volume with ddH_2O. Treatment solutions were stored at 4°C until day of processing.

Ground Beef Preparation

Ground beef was prepared from clods derived from normal pH young beef (YN), dark cutting, high pH young beef (YH), normal pH mature beef (MN), and dark cutting, high pH mature beef (MH) carcass clods (Fig. 1). Clods were completely trimmed for external fat and connective tissue. Each meat type was ground separately first with a coarse plate (1.27cm) followed by fine grinding using a 0.48cm plate. Each meat type was divided into four equal parts and randomly assigned to one of four treatments: Control, AA, XG/AA, or KF/AA. Treatments were added at a 12% level (w/w) and mixed by hand for 2 min. Control meat was mixed in the same manner but without added treatment. Standard food-service ground beef patties (113.5g, 11.5cm dia, 8mm thickness) were formed from each meat type/treatment combination. pH (Model HI98230; Hanna Instruments, Woonsocket, Ri., U.S.A.) was taken on each treatment within each animal type. One raw patty from each day was frozen immediately for moisture and fat determinations which was performed using a CEM SMARTTrac system (CEM Corp., Matthews, Nc., U.S.A) (Keeton and others 2003).

Cooking and Holding

All patties were cooked and held on food-service style aluminum trays that were covered with foil and sprayed with non-stick cooking spray. Cooking took place in a forced-air convection oven (Hobart Corp., Troy, Oh., U.S.A.) at 167°C. Warm holding of patties was done in a Hatco Cook and Hold Oven (Model CSC-10; Hatco Corp., Milwaukee, Wi., U.S.A.) or forced air convection oven at 76.7°C. Patties from all treatments were assigned a cooking and holding environment: dry or moist. An internal cooking temperature was also assigned: 65.6°C, 71.1°C, or 76.7°C (Figure 1). Moist cooking and holding had two cups of water added to the tray which was then covered with aluminum foil. Different cooking and holding treatments were cooked separately. All trays were held then for four hours. Each meat type's evaluation was conducted on a different day and three replications of each meat type were performed.

External Color Evaluation

Patties from each meat type, treatment, cooking method, internal cooking temperature, and holding method were evaluated for external pink color and CIE color

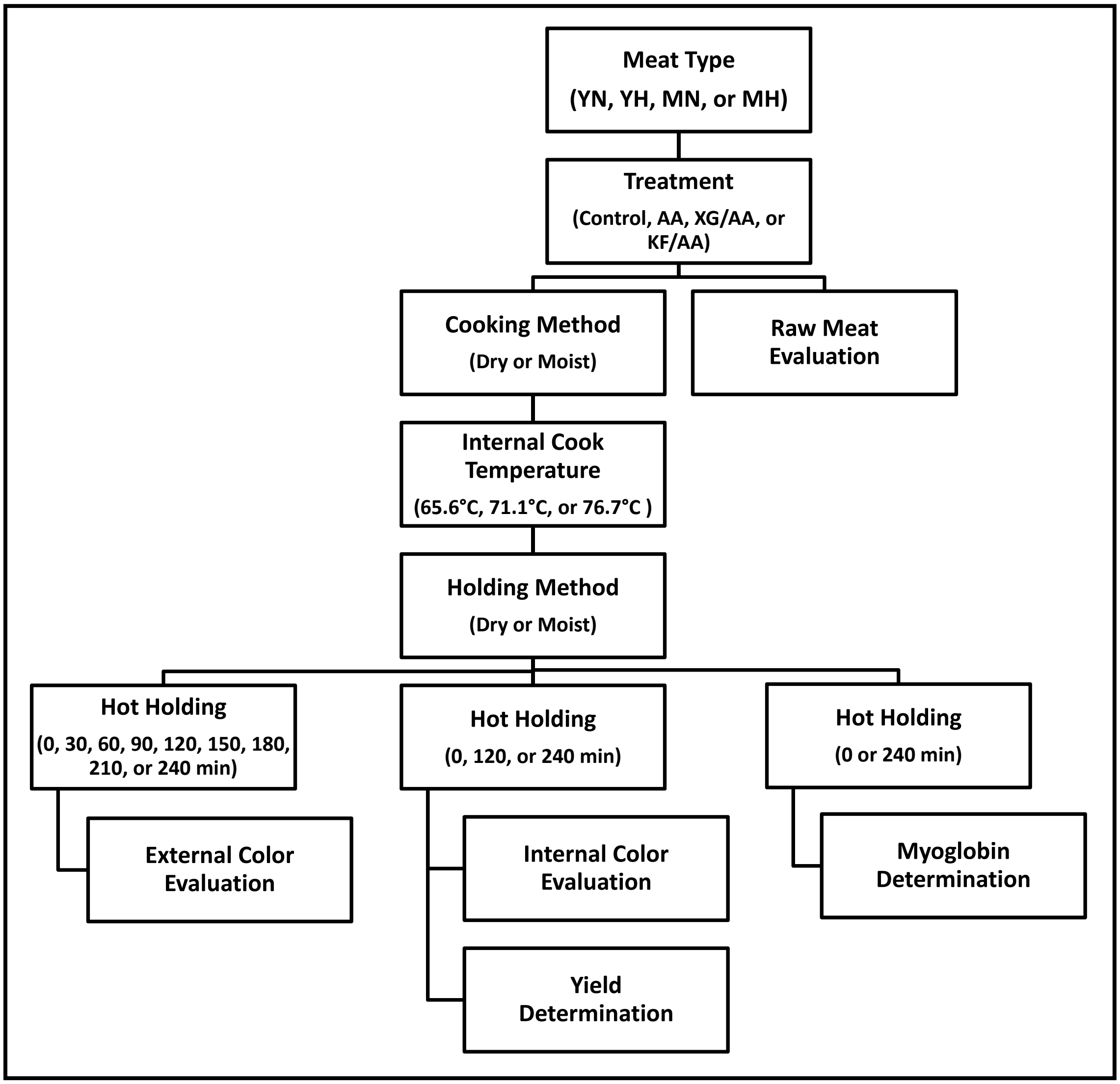

Figure 1. Ground beef patty processing, cooking, holding, and evaluation scheme.

space values at 30 minute intervals during four hours of hold time. External pink color was based on the scale by Hunt and others (1999): 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink. Scores two to five were equal to those of values of one to four on the Ground Beef Patty Cooked Color Guide (Marksberry and others 1993) and a score of one in our study was not included in Marksberry and others. Two trained panelists scored color while patties remain on cooking or holding trays under florescent lighting to the nearest 0.5 point. Color panelists were trained according to the Guidelines for Meat Color Evaluation (AMSA 1991). The CIE L*, a*, and b* color space values were measured using a Hunter MiniScan Plus XE (model 45/0 LAV, Hunter Associates Laboratory, Inc., Reston, Va., U.S.A.) with 10° standard observer, illuminant A, and aperture size of 1.27cm. Calibration of the colorimeter was done at the beginning of each day prior to cooking using a standard white tile and black glass. Chroma was calculated from CIE a* and b* color space values by the formula $(a^{*2} + b^{*2})^{1/2}$.

Internal Color Evaluation

Patties from each meat type, treatment, cooking method, internal cooking temperature, and holding method were evaluated for internal degree of doneness and CIE color space values every two hours of hold time. Patties were sliced parallel to the diameter of the patties resulting in two slices. The CIE L*, a*, and b* color space values and chroma was determined as described for external color. Internal degree of doneness was reported based on the Ground Beef Patty Cooked Color Guide (Marksberry and others 1993) with 1 = raw red center, pink border, tan edge (medium rare); 2 = reddish-pink center, pink border, tan edge; 3 = slightly pink center, light brown to tan edge (medium); 4 = tan/brown center and edges, no evidence of pink (well done); 5 = dry, brown throughout (very well done). Two trained panelists scored color to the nearest 0.5 point while patties were under florescent lighting. Color panelists were trained according to the Guidelines for Meat Color Evaluation (AMSA 1991).

Cook Yield

Yield determinations took place at 0, 2, and 4 hours after cooking and during the holding for each meat type, treatment, cooking method, internal cooking temperature, and holding method. Weight prior to cooking and after each hold time was determined. Cook yield percent was calculated as [(cooked weight/raw weight) × 100].

Denatured Myoglobin

The procedure outlined by Ryan and others (2006), as modified by Warriss (1979) and Hunt and others (1999), was utilized to determine percent denatured myoglobin. A raw patty was used for initial myoglobin concentration and for comparison with cooked patties. For each patty, 6 g of meat was homogenized with 30 mL of 40mM phosphate buffer at pH 6.8. Samples were then stored in a dark cooler at 4°C for 1 hour and centrifuged for 30 minutes at 15,000 × g and 4°C. The supernatant, 2mL, was syringe filtered (BD Luer-loc syringes with VWR 0.45 µm cellulose acetate membrane filter) into a cuvette. A small amount of sodium hydrosulfite was added to convert myoglobin to deoxymyoglobin for detection purposes. Absorbance was read at 433nm on a spectrophotometer (Genesys 10UV; Thermospectronic, Rochester, Ny., U.S.A) and the absorbance was used to calculate myoglobin concentrations using 16,800 for the molecular weight of myoglobin, 114×10^3 $cm^{-1}mM^{-1}$ for the extinction coefficient. Percentage of denatured myoglobin was calculated: [(initial myoglobin - undenatured myoglobin)/initial myoglobin] × 100. Quantification was performed in duplicate.

Statistical Analysis

Individual patties were defined as an experimental unit. Data was analyzed using the Proc Mixed procedure of SAS (Ver. 9.1, SAS Inst., Cary, NC, 2003) where six fixed effects (meat type, treatment, cooking method, internal cooking temperature, holding method, and holding time) were defined in the model. Two-way interactions were also included in the model and replication was added as a random effect. Insignificant interactions ($P>0.05$) were removed from the model for final analysis. Least squares means were calculated and significant ($P<0.05$) least squares means were separated using the pdiff function.

CHAPTER IV

RESULTS AND DISCUSSION

Meat Type

Raw ground beef varied in fat and moisture content based on the source of the beef clods. The meat from mature animals was lower in fat than the meat from young animals (Table 1). The MN ground beef had the highest percentage of moisture (76.45%) and the lowest percentage of fat (0.75%). Meat from YN animals was lowest in moisture (72.21%). The highest percentage of fat was observed in the patties made from young meat. Though external fat was completely trimmed, the internal fat differences were apparent between the meat from young animals and the meat from mature animals. Differences in cooked ground beef patty attributes have been found in previous studies. When patties varied in fat content (3 versus 20%), the external color of the patties were not different (Moiseev and Cornforth 1999) nor was the cook yield or cook time in patties containing 5, 10, 15, 20, and 25% fat (Berry 1998b). Patties that were higher in fat (20-28%) were browner and less pink internally than lower fat (6-10%) patties (Berry and Bigner-George 2000).

Raw pH was highest in the MH ground beef and lowest for the YN ground beef at 6.14 and 5.72, respectively (P<0.0001) (Table 2). The pH of meat that was from MN and YH did not differ and was in-between the ground beef of the other two meat sources. Many studies have evaluated the effects of pH on the cooked color of red meats and

Table 1. Least squares means for percent moisture and fat of raw ground beef for meat type by replication.

Effect	Moisture (%)	Fat (%)
RMSE[a]	1.14	0.60
Meat Type[b]	<0.0001	<0.0001
Mature-High pH	76.45[f]	0.75[c]
Mature-Normal pH	74.84[e]	1.58[d]
Young-High pH	73.42[d]	3.02[e]
Young-Normal pH	72.21[c]	3.59[e]

[a]Root mean square error from analysis of variance tables.
[b]*P*-value from analysis of variance tables.
[cdef]Mean values within a column and followed by the same letter are not significantly different ($P>0.05$).

some have attributed this as one of the main contributors to cooked color development or lack there of (Trout 1989; Mancini and others 2005).

Cook time and percent cook yield differed due to meat source (Table 2). Cooking time for the MH and YH ground beef patties was shorter than cooking time for the YN ground beef patties (P=0.0038). Yield was highest for the patties that were made from high pH meat and lowest for patties made from normal pH meat (P<0.0001). This is explained by the higher pH having more water bound to the meat proteins (Zayas 1997) reducing water loss during cooking and hot holding compared to normal pH meat. Brewer and Novakofski (1999) and Young and others (2005) indicated that cook loss of ground beef patties was highest when the pH was closest to the isoelectric point (pH 5.0-5.1); the current study complemented these results. Though not supported by the present research, two evaluations founds that 10% or 18% fat ground beef patties [young meat source] had greater yields than cow meat patties [mature meat source] (Berry 1997; Berry and Bigner-George 1999). Berry (1998a) compared ground beef patties from 3 and 10 yr old animals, as well as ground beef patties made from normal and high, young meat sources. There were no differences in cook time of ground beef patties from animals of 3 and 10 yrs of age, but cook time increased for patties that were from high pH fed-beef [younger animals]. This study also found that ground beef patties that were made from mature animals (10 yrs of age) had higher yields than meat from 3 yr old animals or from high pH young animals. Though not an exact comparison, the present study had the greatest yields in the high pH, mature meat sourced patties.

Table 2. Least squares means for raw pH, cook time, and cook yield of ground beef patties as affected by meat type, cooking method, internal cook temperature, holding method, and holding time.

Effect	pH	Cook Time, min	Cook Yield (%)[a]
RMSE[b]	0.15	2.08	5.43
Meat Type[c]	<0.0001	0.0038	<0.0001
Mature-High pH	6.14[f]	10.5[d]	72.46[e]
Mature-Normal pH	5.89[e]	10.8[de]	70.53[d]
Young-High pH	5.81[e]	9.8[d]	71.77[e]
Young-Normal pH	5.72[d]	11.6[e]	69.96[d]
Cooking Method[c]		<0.0001	0.0007
Dry	-	9.1[d]	71.63[e]
Moist	-	12.3[e]	70.74[d]
Internal Cook Temperature, °C[c]		<0.0001	<0.0001
65.6	-	9.4[d]	73.77[e]
71.1	-	11.1[e]	69.88[d]
76.7	-	11.5[e]	69.89[d]
Holding Method[c]			<0.0001
Dry	-	-	67.79[d]
Moist	-	-	74.58[e]
Holding Time, min[c]			<0.0001
0	-	-	76.38[f]
120	-	-	71.67[e]
240	-	-	65.50[d]

[a]Cook yield = (cook weight/raw weight) × 100.
[b]Root mean square error from analysis of variance tables.
[c]*P*-value from analysis of variance tables.
[def]Mean values within a column and followed by the same letter are not significantly different (*P>0.05*).

Internal cooked color differences were observed in all measurements (Table 3). The CIE L* color space values showed that MN meat source was the lightest, followed by MH, then YH and lastly the YN ground beef patties were the darkest in color ($P<0.0001$). Ground beef patties from MH meat had the highest a* and b* values followed by YH and MN, and then YN patties had the lowest CIE a* and b* values ($P<0.0001$). Various results have been found in previous studies. Ground beef patties from cow [mature] sources and USDA Select chucks did not differ in CIE L*, a*, and b* values (Berry and Bigner-George 1999). Higher a* values have been reported in DFD cooked meat products when compared to meat from normal pH sources (Mendenhall 1989; Berry 1998a; Lien and others 2002).

Internal degree of doneness tended to be different than CIE color space values. The MN meat source appeared the least done or had the lowest internal color score followed by MH, YH and then YN source, which had the highest degree of doneness score ($P<0.0001$). The ground beef patties made from the YN meat source had the most done appearance for all internal color attributes. This was expected and is further confirmed by the percent of denatured myoglobin in these patties being the highest at 82.16% ($P<0.0001$). The patties made from MH meat had the least myoglobin denaturation at 56.83% and intermediate denaturation occurred in MN and YH ground beef patties. Degree of doneness scores reported by other investigators were also lower for both DFD meat products (van Laack and others 1997) and for meat products made from cow meat [mature meat source] (Berry 1998a; Berry and Bigner-George 1999) as compared with normal pH and young meat sources, respectively. Only one study found

Table 3. Least squares means for internal color attributes and denatured myoglobin of cooked ground beef patties as affected by meat type, cooking method, internal cook temperature, holding method, and holding time.

Effect	CIE Color Space Values L*	a*	b*	Internal Doneness[a]	Myoglobin, Denatured (%)[b]
RMSE[c]	6.39	3.56	2.09	0.60	15.17
Meat Type[d]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Mature-High pH	48.09[g]	18.58[h]	18.84[h]	3.43[f]	56.83[e]
Mature-Normal pH	52.17[h]	15.50[f]	16.68[f]	3.31[e]	67.93[f]
Young-High pH	46.39[f]	16.08[g]	17.12[g]	3.61[g]	70.88[g]
Young-Normal pH	41.96[e]	12.86[e]	14.86[e]	4.04[h]	82.16[h]
Cooking Method[d]	0.5617	0.0236	0.0612	0.3514	0.7930
Dry	47.24	15.95[f]	16.97	3.58	69.33
Moist	47.06	15.56[e]	16.78	3.61	69.57
Internal Cook Temperature, °C[d]	0.0308	<0.0001	<0.0001	<0.0001	<0.0001
65.6	47.71[f]	17.36[f]	17.47[f]	3.27[e]	61.67[e]
71.1	47.00[ef]	15.15[e]	16.64[e]	3.71[f]	72.38[f]
76.7	46.74[e]	14.77[e]	16.51[e]	3.81[g]	74.30[f]
Holding Method[d]	0.7461	<0.0001	<0.0001	<0.0001	0.3018
Dry	47.20	14.95[e]	16.53[e]	3.78[f]	68.99
Moist	47.10	16.56[f]	17.22[f]	3.41[e]	69.91
Holding Time, min[d]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
0	46.21[e]	16.75[f]	17.33[f]	3.37[e]	67.58[e]
120	47.69[f]	16.59[f]	17.23[f]	3.41[e]	-
240	47.56[f]	13.94[e]	16.07[e]	4.02[f]	71.32[f]

[a]Internal Degree of Doneness: 1 = raw red center, pink border, tan edge (medium rare); 2 = reddish-pink center, pink border, tan edge; 3 = slightly pink center, light brown to tan edge (medium); 4 = tan/brown center and edges, no evidence of pink (well done); 5 = dry, brown throughout (very well done).
[b]Percent of denatured myoglobin = [(total myoglobin – denatured myoglobin)/total myoglobin] × 100.
[c]Root mean square error from analysis of variance tables.
[d]*P*-value from analysis of variance tables.
[efgh]Mean values within a column and followed by the same letter are not significantly different (*P>0.05*).

no difference in degree of doneness scores from young and old animal sources in ground beef patties (Berry 1997). Myoglobin denaturation has also been evaluated. Studies have shown that the percentage of myoglobin denaturation is less in meat with a higher pH (Mendenhall 1989; Trout 1989; van Laack and others 1996b) and in higher pH meats, the myoglobin denatures at a slower rate (Lytras and others 1999).

External cooked color varied for CIE L*, a*, and b* color space values, chroma and external pink color (Table 4). The CIE L* values were highest for the MN ground beef patties followed by YH, YN and lastly, the MH patties had the lowest L* values ($P<0.0001$). Ground beef patties from YH were the most red externally (a*) ($P<0.0001$) and yellow (b*) ($P<0.0001$) and MN beef patties were the least for these attributes. The external color values did not favor the hypothesis that lowest color space values, especially a* and b*, would be observed in the YN patties and the opposite in the MH patties. It appears that other color attributes were masked by the darkening (lower L* values) on the surface of the patties and the initial darkness of the mature meat. External pink color was not different for YH and MN ground beef patties which were intermediate to the least pink YN patties and the most pink MH patties ($P<0.0001$). External pink color followed the expected tendency with YN patties having the most done appearance and MH having the least done appearance. These data were different from that reported by Moiseev and Cornforth (1999) who found no difference in external patty color due to the pH of the raw meat source.

Meat type greatly affected the cooked color development in ground beef patties. Internal color differences were more pronounced than external color attributes. This is

Table 4. Least squares means for external color attributes of cooked ground beef patties as affected by meat type, cooking method, internal cook temperature, holding method, and holding time.

Effect	CIE Color Space Values L*	a*	b*	External Pink Color[a]
RMSE[b]	7.91	2.56	3.34	0.33
Meat Type[c]	<0.0001	<0.0001	<0.0001	<0.0001
Mature-High pH	34.16^{d}	13.52^{f}	14.59^{e}	4.73^{d}
Mature-Normal pH	42.58^{g}	12.46^{d}	14.05^{d}	4.80^{e}
Young-High pH	37.44^{f}	14.23^{g}	16.15^{g}	4.81^{e}
Young-Normal pH	36.20^{e}	12.91^{e}	15.26^{f}	4.86^{f}
Cooking Method[c]	<0.0001	0.0183	<0.0001	<0.0001
Dry	35.50^{d}	13.37^{e}	14.56^{d}	4.87^{e}
Moist	39.69^{e}	13.19^{d}	15.46^{e}	4.73^{d}
Internal Cook Temperature, °C[c]	<0.0001	<0.0001	<0.0001	<0.0001
65.6	38.63^{e}	14.04^{e}	15.63^{f}	4.73^{d}
71.1	36.90^{d}	12.88^{d}	14.50^{e}	4.83^{e}
76.7	37.25^{d}	12.93^{d}	14.91^{d}	4.84^{e}
Holding Method[c]	<0.0001	0.3784	<0.0001	0.0805
Dry	34.41^{d}	13.32	13.35^{d}	4.79
Moist	40.78^{e}	13.25	16.68^{e}	4.81
Holding Time, min[c]	<0.0001	<0.0001	<0.0001	<0.0001
0	43.38^{i}	15.63^{j}	18.75^{l}	4.33^{d}
30	40.21^{h}	14.40^{i}	17.38^{k}	4.70^{e}
60	38.92^{g}	14.24^{i}	16.68^{j}	4.78^{f}
90	38.56^{g}	13.80^{h}	16.00^{i}	4.81^{f}
120	37.01^{f}	13.30^{g}	14.90^{h}	4.87^{g}
150	36.63^{f}	13.04^{g}	14.31^{g}	4.82^{fg}
180	35.24^{e}	12.43^{f}	13.31^{f}	4.93^{h}
210	35.14^{e}	11.62^{e}	12.38^{e}	4.97^{h}
240	33.28^{d}	11.07^{d}	11.41^{d}	4.99^{h}

[a]External Pink Color: 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink.
[b]Root mean square error from analysis of variance tables.
[c]*P*-value from analysis of variance tables.
[defghijkl]Mean values within a column and followed by the same letter are not significantly different (*P>0.05*).

probably due to exterior portion of the patties receiving the greatest amount of heat and therefore more severe myoglobin denaturation, whereas the interior portion of the patties received the least amount of direct heat. As expected, YN patties had the most done appearance internally as well as the greatest percentage of denatured myoglobin. Generally, the YH and MN patties were similar – possibly indicating that the effect of higher total myoglobin and higher pH affected the cooked color in similar ways, although the mechanisms maybe completely different. The MH patties did not appear as cooked which was supported by their high internal a* color space values, low degree of doneness scores, low percentage of myoglobin denaturation, and low external pink scores. These data support that meat sources influences color development in cook ground beef patties.

Cooking Method

Dry and moist cooking where evaluated because they are both used in common foodservice style cooking. Cooking time and yield differed based on the method of cooking (Table 2). Cooking time was significantly longer for patties in the moist method (12.3 min) compared to the dry method (9.1 min) (P<0.0001). This was most like due to the water in the pans need to heat before the patties could start to heat. Additionally, cook yield was lower in the ground beef patties cooked in the moist method compared the dry method (P=0.0007). The difference in yield is most likely due to the 3 minute longer cook time for the moist cooking method that was observed; however, it was expected that the dry method would have lower yield than the moist method. Many studies have compared dry cookery methods, pan-frying, broiling, roasting, microwaving, grilling, convection oven. Differences in cook yield were not reported between dry cooking methods when patties were cooked to the same end-point temperature (Hoelscher and others 1987; Berry 1994; Berry and Abraham 1996) and cook yield was higher in patties cooked using a broiling/grilling combination as compared with an impingement oven (Berry 1997). Additionally, low-fat ground beef patty formulation [meat source and ingredients] had a greater effect on cooking characteristics than cooking method (Berry 1997).

The CIE a* color space values were the only internal color attribute that differed due to cooking method (P=0.0236) (Table 3). Though these differences were quite small, the dry cooking method produced ground beef patties that were redder than the patties from the moist cooking method. Internal CIE L* and b* color space values, degree of doneness and denatured myoglobin did not differ between the two cooking methods. Ryan and others (2006) reported that slowly cooking patties versus rapid cooking resulted in patties that were more done in appearance and had a greater percentage of denatured myoglobin.

Cooking method by meat type interactions occurred for internal CIE a* and b* color space values (P<0.05) (Figure 2). There was no difference for internal CIE a* color space values between the dry and moist cooking except for the patties that were made from MN. These patties were less red when cooked in the moist environment. Yellowness (b*) was lower for normal pH patties cooked in a moist atmosphere compared to a dry atmosphere. The patties made of MH meat had lower CIE b* color

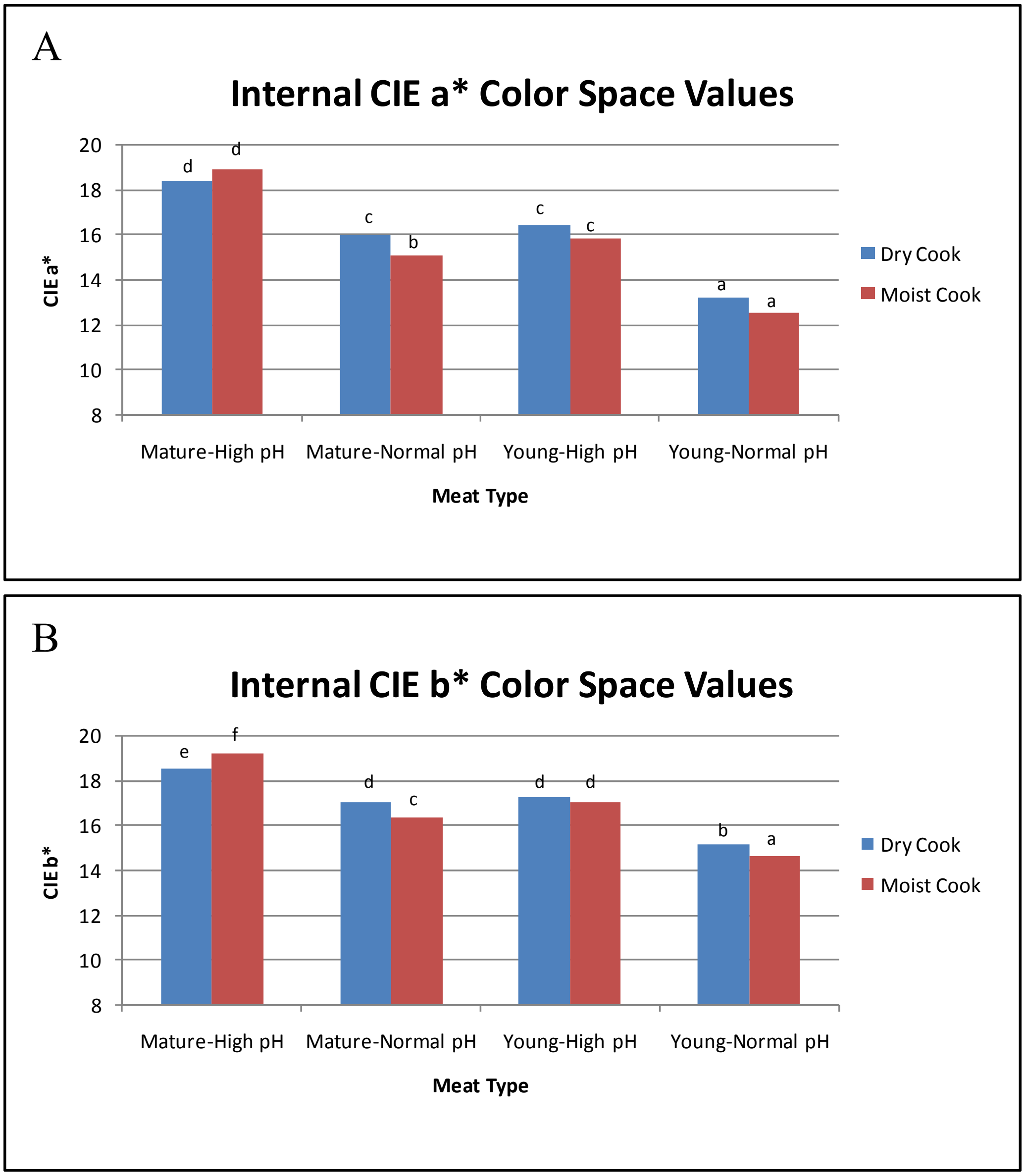

Figure 2. Least squares means for meat type and cooking method interactions for internal CIE (A) a* (P=0.0195[g]) and (B) b* (P<.0001[g]) color space values.

[a-f]Mean values followed by the same letter are not significantly different ($P>0.05$).
[g]P-value from analysis of variance tables.

space values when dry cooked compared to moist cooked and the YH meat patties did not differ in CIE b* color space values between cooking methods.

Cooking method by meat type interactions occurred for denatured myoglobin (*P*<0.05) (Figure 3). Percent of denatured myoglobin did not differ between dry and moist cooking within each meat type. The MH ground beef patties had the least amount of denaturation and YN meat produced patties that had the highest amount of denaturation with MN and YH having about the same denaturation. This was expected and correlates with the results that were discussed in the meat type section and the results by Berry (1997) where they found that the meat type had a greater effect on the color than did the cooking method.

External color attributes all differed due to cooking method (Table 4). The moist cooking method produced patties that were lighter (*P*<0.0001) and more yellow (*P*<0.0001) when compared to the dry cooking method. Dry cooked patties were slightly redder (*P*<0.0001) and had higher external pink color scores (*P*<0.0001) than patties from the moist cooking method.

External CIE color space values (Figure 4) and external pink color (Figure 5) were each affected differently based on meat type and cooking environments (*P*<0.05). The CIE L* color space values for the dry cooking method were lower than the moist cooking method within each meat type. Ground beef patties from MH meat that were dry cooked had the lowest L* values while the highest L* values were seen in the MN moist cooked ground beef patties. There was not a general trend for external CIE a* values. The MH patties were redder when cooked using moisture, whereas MN and YH

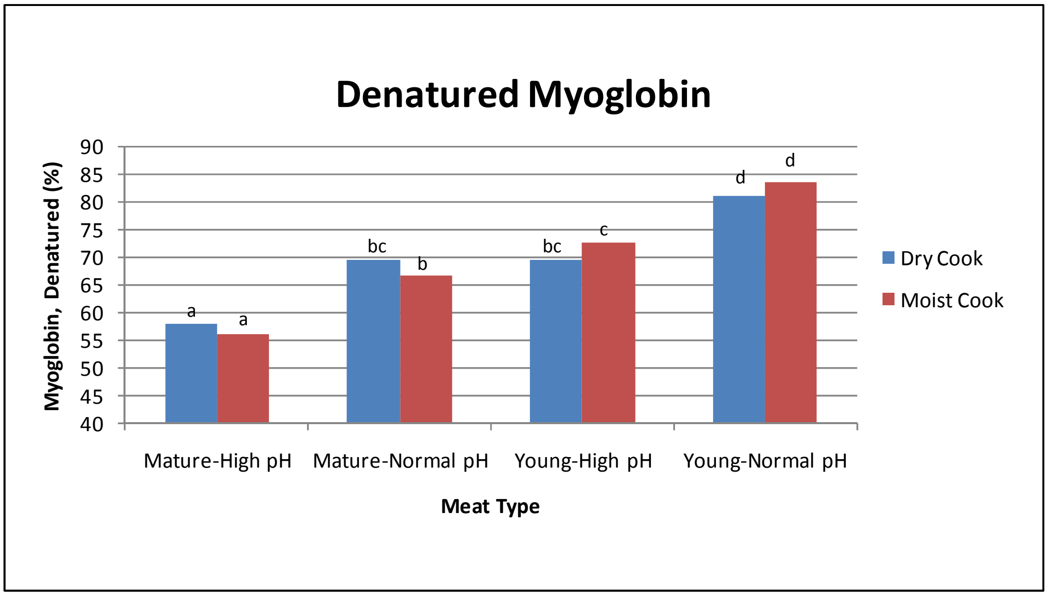

Figure 3. Least squares means for meat type and cooking method interaction for denatured myoglobin[e] (*P*=0.0471[f]).

[a-d]Mean values followed by the same letter are not significantly different (*P>0.05*).
[e]Percent of denatured myoglobin = [(total myoglobin – denatured myoglobin)/total myoglobin] × 100.
[f]*P*-value from analysis of variance tables.

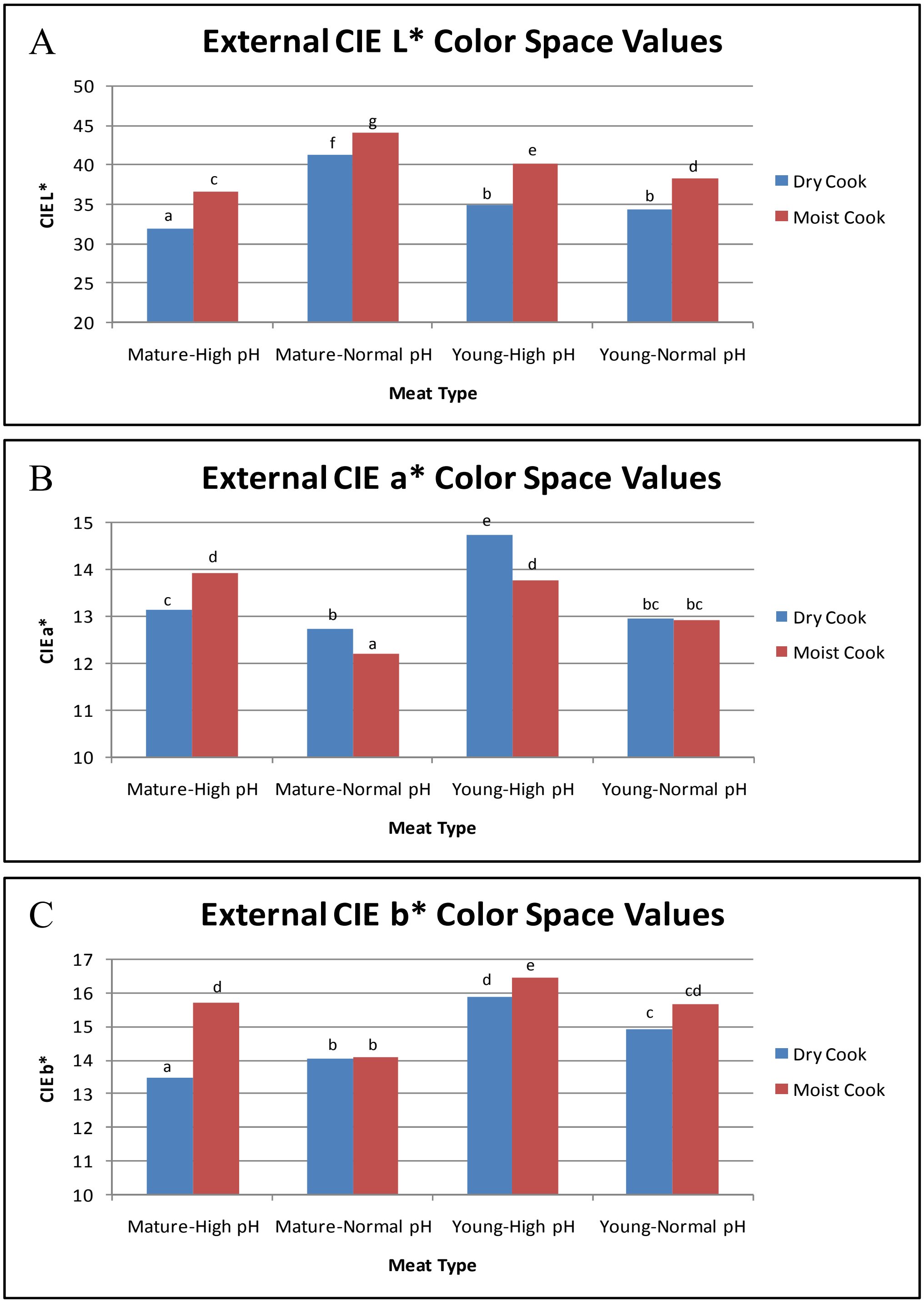

Figure 4. Least squares means for meat type and cooking method interactions for external CIE (A) L* (*P*=0.0006[h]), (B) a* (*P*<.0001[h]), and (C) b* (*P*<.0001[h]) color space values.

[a-g]Mean values followed by the same letter are not significantly different (*P>0.05*).
[h]*P*-value from analysis of variance tables.

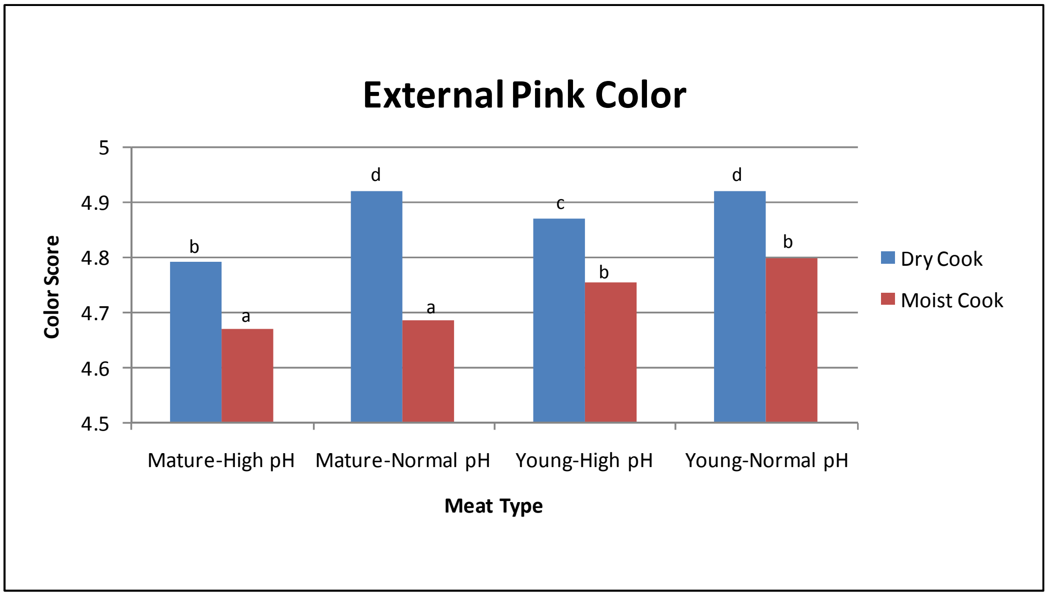

Figure 5. Least squares means for meat type and cooking method interaction for external pink color[e] (*P*=0.0003[f]).

[a-d]Mean values followed by the same letter are not significantly different ($P>0.05$).
[e]External Pink Color: 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink.
[f]*P*-value from analysis of variance tables.

ground beef patties were redder when subjected to dry cooking. No difference was observed between cooking methods for patties of YH meat. The normal pH meat patties had the lowest a* values overall than the high pH patties. In contrast to other trends observed and what was expected, the MN patties in moist cooking had the lowest external a* values. The lowest a* values was expected to be observed in the YN patties. Ground beef patties from normal pH meats did not differ in CIE b* values between cooking methods. The high pH patties had lower b* values when cooked using the dry method than the moist method. Young meat sources resulted in ground beef patties that were more yellow than the ground beef patties from mature meat sources. Meat patties cooked in a moist environment had lower external pink scores (less done appearance) than patties in the same meat type cooked in a dry environment. The highest external pink scores were observed in the normal pH/dry cooked patties. The mature patties in moist cooking had the lowest external pink scores (most pink) compared to the moist cooked young meat patties. The MH patties that were dry cooked only equaled that of the young patties that were moist cooked.

Therefore, cooked color of ground beef patties varying in meat source differed when cooked in a dry or moist environment. The greatest effect of cooking method on the color attributes was on the external color over the internal color and denatured myoglobin. Moisture is used in food service to increase juiciness of subsequent cooked ground beef patties. However, this resulted in patties with a less done appearance – had lower external pink scores – than the dry cooked patties.

Internal Cook Temperature

The effect of internal cook temperature was evaluated for its effects on cooking time and yield and cooked color attributes. Internal cook time along with pH is one of the main contributors to cooked color development in ground beef patties (Mancini and others 2005). Cook time was shortest for the patties cooked to 65.6°C with no difference in the two cook temperatures (*P*<0.0001) (Table 2). Cook time typically increases with increasing cook temperatures (Liu and Berry 1996; Berry 1998a; Berry and Bigner-George 1999; Ryan and others 2006). Typically, cook yield decreases with increasing cook temperatures (Kregel and others 1986; Troutt and others 1992; Berry 1994; Berry and Bigner-George 1999; Hunt and others 1999) and was observed for the patties that were at the 65.6°C and 71.1°C cook temperatures, however, no differences in cook yield were seen with the increase from 71.1°C to 76.7°C (*P*<0.0001) (Table 2). The interaction was significant for cook yield between meat type and internal cook temperature (Figure 6) (*P*<0.05). There was a decrease in cook yield with increasing internal cook temperatures for ground beef patties made from meat from young animals regardless of meat pH. The patties from mature meat had lower cook yields at 71.1°C compared with 65.6°C cooked patties. The cook yield of ground beef patties made from MH had no change in cook yield when temperature increased from 71.1°C to 76.7°C whereas the MN had an increase in yield for this temperature change. Any increase in yield at the higher temperatures was not expected and is not supported by previous literature.

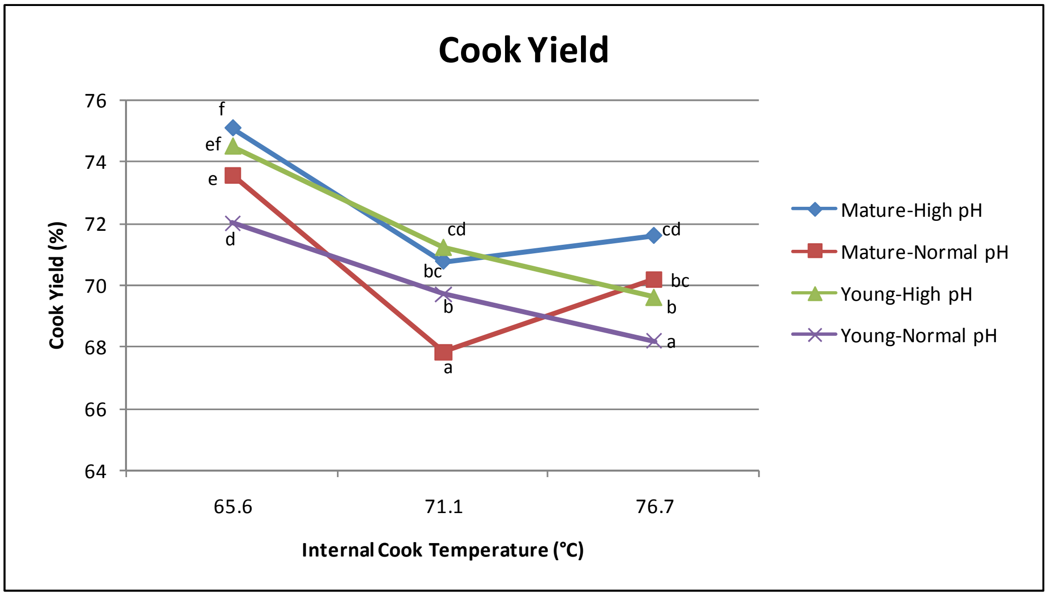

Figure 6. Least squares means for meat type and internal cook temperature interaction for cook yield[g] (P<0.0001[h]).

[a-f]Mean values followed by the same letter are not significantly different (P>*0.05*).
[g]Cook yield = (cook weight/raw weight) × 100.
[h]P-value from analysis of variance tables.

Internal cooked color attributes varied with internal cook temperature (Table 3). The 65.6°C cooked patties were the lightest (*P*=0.0308), most red (*P*<0.0001), most yellow (*P*<0.0001), had the lowest degree of doneness (*P*<0.0001), and the least amount of denatured myoglobin (*P*<0.0001) compared to patties cooked to the higher cook temperatures. As reported for cook time and yield data, the 71.1°C and 76.7°C cooked temperatures did not differ for CIE L*, a*, and b* color space values and percent of denatured myoglobin. Only internal degree of doneness differed for patties cooked to 71.1°C and 76.7°C, where degree of doneness scores were higher in 76.7°C cooked patties. Lavelle (1995) reported a decrease in a* and b* color space values with increasing cook temperatures in ground beef from 55°C, 65°C, 71°C, and 77°C while Liu and Berry (1996) observed a lower a* in patties cooked to 74°C compared to patties cooked to 68°C or 71°C. The current study showed similar results but only when patties were cooked from 65.6°C to 71.1°C, but not with the increase in internal temperature to 76.7°C. In contrast to the current study, Trout (1989) found that as internal cook temperatures (55°C , 62°C, 69°C, 76 °C, and 83°C) increased, percent of myoglobin denaturation also increased.

Berry and Bigner-George (2000) reported an increase in L* values in ground beef patties with an increase in cook temperature from 57°C to 66°C, but there was no difference in L* values with the increase in internal temperature from 66°C to 71°C. This is contrary to the present study where patties cooked from 65.6°C to 71.1°C differed in L* color space values, however the use of an outdoor gas grill compared to a convection oven could contribute to this difference. Studies have found that increased cooking time and internal cook temperature produced more done appearance with less redness (Troutt and others 1992; Berry 1994; Liu and Berry 1996; van Laack and others 1996a; Berry and Bigner-George 1999; Berry and Bigner-George 2000). The results of the present study agree with these findings for L* and a* color space values for the patties cooked to 65.6°C and 71.1°C, but as internal cook temperature increased from 71.1°C to 76.7°C only patty degree of doneness scores increased. There were no changes in L* and a* color space values.

Meat type by internal cook temperature interactions were significant ($P<0.05$) for internal CIE a* color space values (Figure 7), for internal degree of doneness (Figure 8), and for denatured myoglobin (Figure 9). "Hard-to-cook" meats have been defined as meats that do not exhibit normal cooked color characteristics and typically stay red even at temperatures sufficient to brown normal meats (Mendenhall 1989; Trout 1989; Hague and others 1994; van Laack and others 1996b; Hunt and others 1999). The present study would indicate that these "hard-to-cook" meats could include meat from mature animals and meat of higher pH as ground beef patties containing these meat sources had the same uncooked appearance even when fully cooked (temperatures up to 76.7°C). Ground beef patties made from YN and MH meat had a gradual decrease in CIE a* color space values with an increase in internal cook temperature. For YH and MN ground beef patties, there was a decrease in redness (a*) from 65.6°C to 71.1°C. From 71.1°C to 76.7°C, YH ground beef patties did not change in redness, and redness increased for MN patties when cooked to the same endpoint temperature. Redness has been shown to decrease with increasing cook temperatures even in high pH meat sources (Berry 1998a),

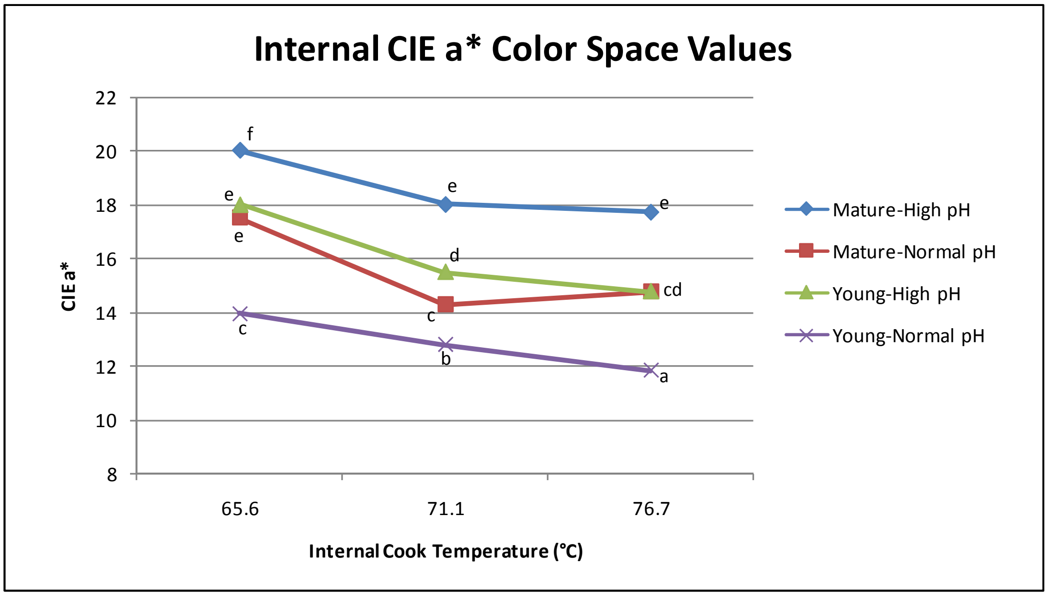

Figure 7. Least squares means for meat type and internal cook temperature interaction for internal CIE a* color space values (*P*=0.0165[g]).

[a-f]Mean values followed by the same letter are not significantly different (*P>0.05*).
[g]*P*-value from analysis of variance tables.

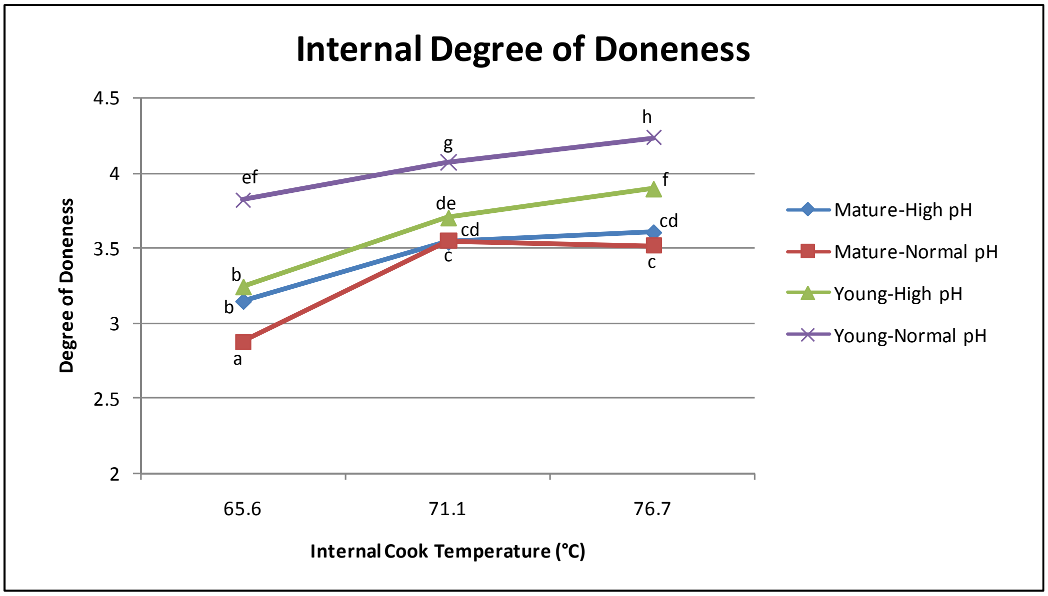

Figure 8. Least squares means for meat type and internal cook temperature interaction for internal degree of doneness[i] (P=0.0071[j]).

[a-h]Mean values followed by the same letter are not significantly different ($P>0.05$).
[i]Internal Degree of Doneness: 1 = raw red center, pink border, tan edge (medium rare); 2 = reddish-pink center, pink border, tan edge; 3 = slightly pink center, light brown to tan edge (medium); 4 = tan/brown center and edges, no evidence of pink (well done); 5 = dry, brown throughout (very well done).
[j]P-value from analysis of variance tables.

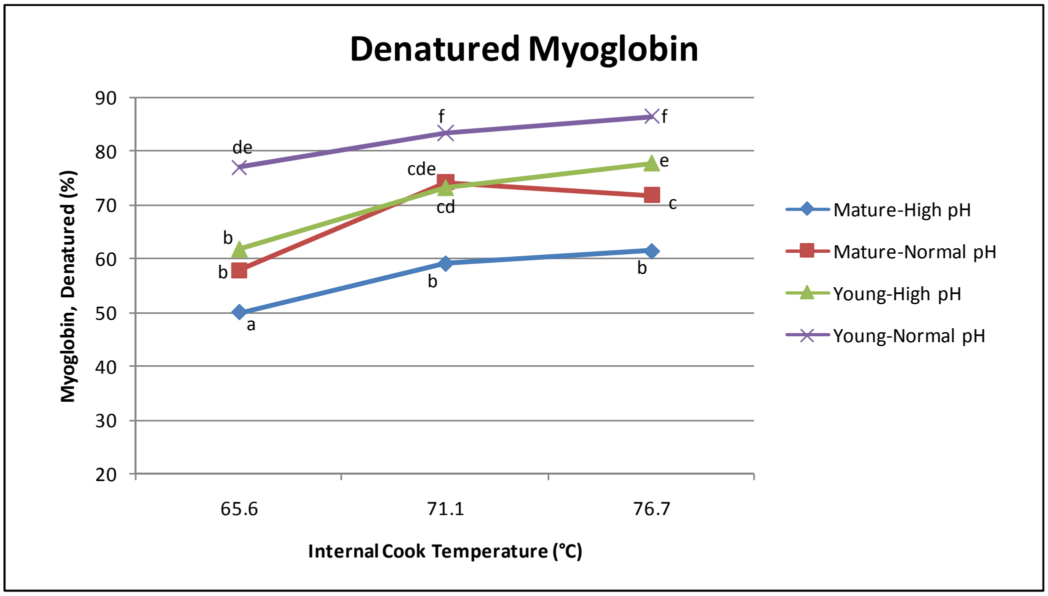

Figure 9. Least squares means for meat type and internal cook temperature interaction for denatured myoglobin[g] (P=0.0313[h]).

[a-f]Mean values followed by the same letter are not significantly different (*P>0.05*).
[g]Percent of denatured myoglobin = [(total myoglobin – denatured myoglobin)/total myoglobin] × 100.
[h]*P*-value from analysis of variance tables.

but usually higher temperatures are required for redness to decrease in patties from high pH meats when compared to normal pH meats (Berry 1997). One study found that there was no difference in color attributes when patties were cooked to 68°C and 71°C (van Laack and others 1997). In the current study, there was an increase in internal perceived doneness with an increase in internal cook temperature with the exception of the ground beef patties from the mature animal sources that did not change in doneness scores when patties were cooked from 71.1°C to 76.7°C. The highest amount of myoglobin denaturation occurred when patties were cooked from 65.6°C to 71.1°C. There was no change in the percent myoglobin denaturation for YN, MH, and MN meat sources cooked from 71.1°C to 76.7°C. The YH meat had an increase in myoglobin denaturation as cook temperature increased. In pork chops, Lien and others (2002) noted that pork chops with a lower pH had greater myoglobin denaturation compared to meat with a higher pH and that myoglobin denaturation occurred at a faster rate. As longer cook times were needed to reach the higher cook temperatures, it would be expected that there would be a greater amount of myoglobin denaturation in the ground beef patties cooked to higher internal temperatures. Heat denaturation of myoglobin occurred at lower temperatures when meat pH was lower compared to myoglobin denaturation in high pH meat that required higher temperatures (Mendenhall 1989; Brewer and Novakofski 1999).

Cooking method and internal cook temperature interactions were significant ($P<0.05$) for internal CIE a* and b* color space values (Figure 10) and for internal degree of doneness (Figure 11). The a* values for dry cooking decreased as temperature

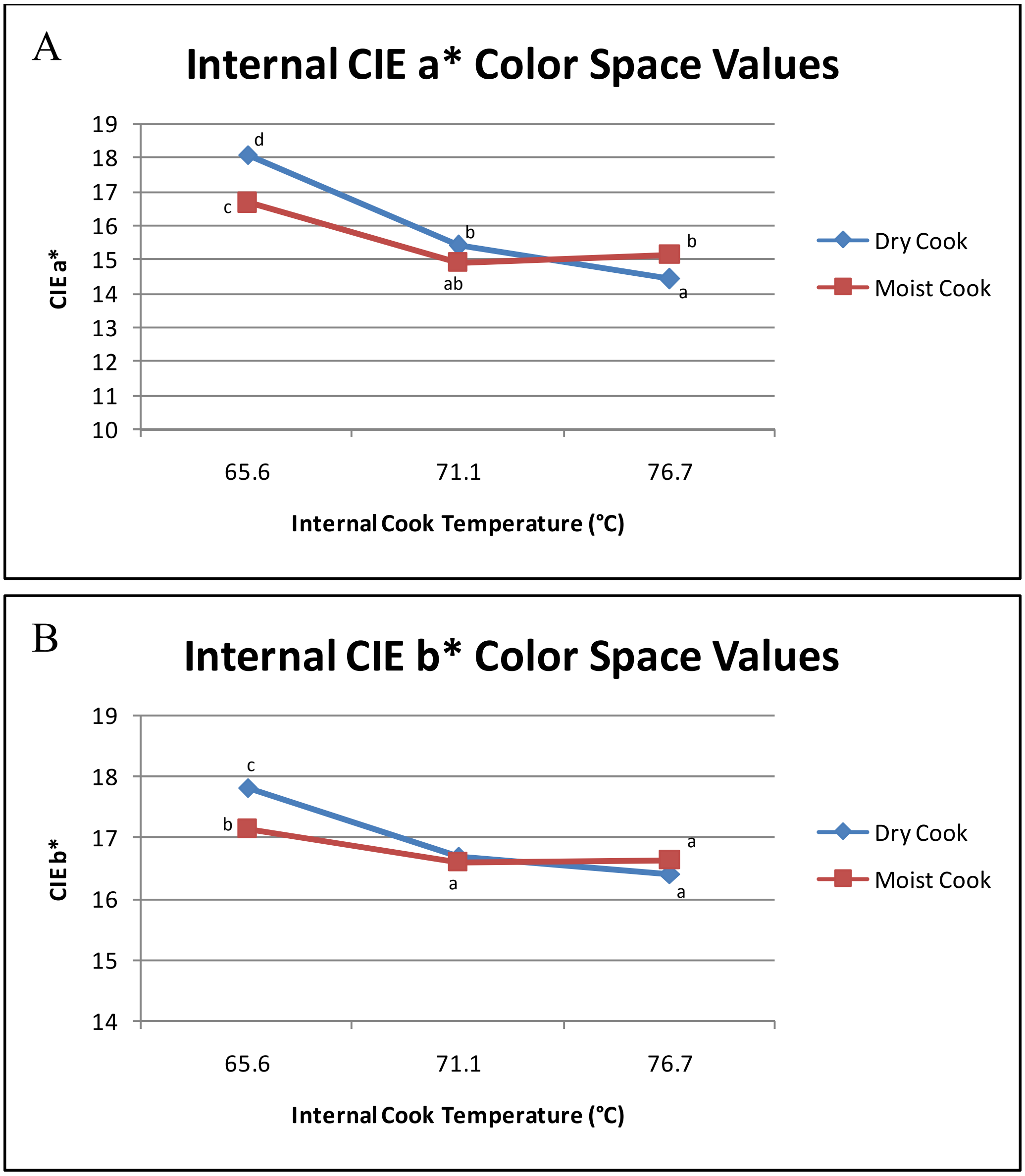

Figure 10. Least squares means for cooking method and internal cook temperature interactions for internal CIE (A) a* (*P*<0.0001[e]) and (B) b* (*P*=0.0013[e]) color space values.

[a-d]Mean values followed by the same letter are not significantly different (*P>0.05*).
[e]*P*-value from analysis of variance tables.

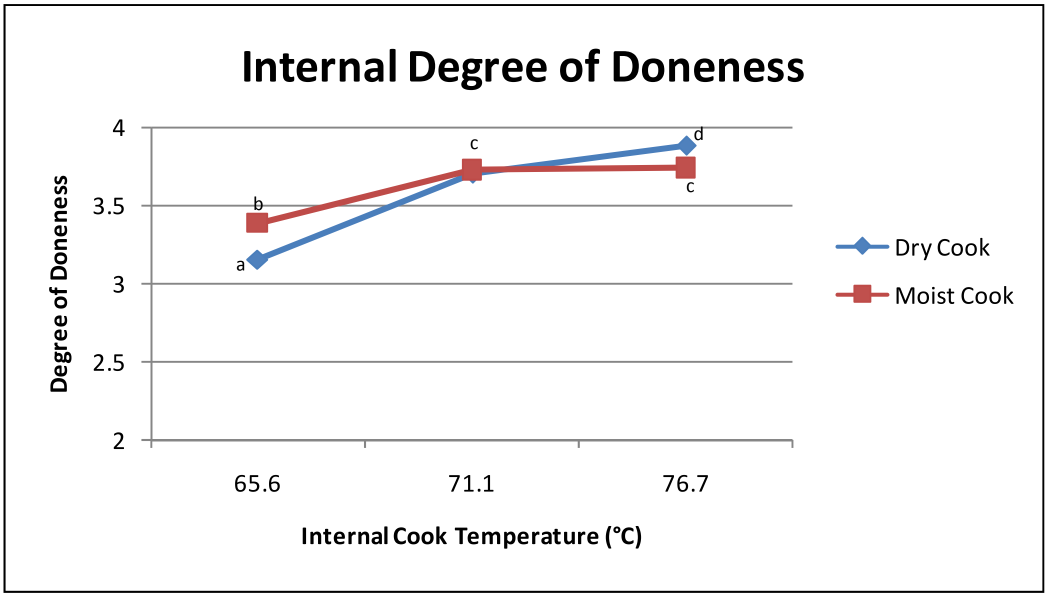

Figure 11. Least squares means for cooking method and internal cook temperature interaction for internal degree of doneness[e] (P<0.0001[f]).

[a-d]Mean values followed by the same letter are not significantly different ($P > 0.05$).
[e]Internal Degree of Doneness: 1 = raw red center, pink border, tan edge (medium rare); 2 = reddish-pink center, pink border, tan edge; 3 = slightly pink center, light brown to tan edge (medium); 4 = tan/brown center and edges, no evidence of pink (well done); 5 = dry, brown throughout (very well done).
[f]*P*-value from analysis of variance tables.

increased. Dry cooking produced patties that were more red and yellow than patties cooked using moist cooking at 65.6°C. For patties cooked to 71.1°C and 76.7°C, cooking methods did not affect color space values except patties cooked using the dry method had lower a* color space values than patties cooked using the moist cooking method. Moist cooking of patties reduced a* and b* color values from 65.6°C to 71.1°C but there was no difference in a* and b* color space values for patties cooked to 71.1°C and 76.7°C. Visual degree of doneness scores did not change with subsequent cooking from 71.1°C. Dry cooked patties had the lowest degree of doneness scores at 65.6°C and the highest degree of doneness scores were observed in dry cooked patties at 76.7°C. Moist and dry cooking methods did not differ in internal degree of doneness scores when cooked to 71.1°C.

External color values showed similar results as those reported for internal color traits (Table 4). The CIE L* (P<0.0001), a* (P<0.0001), and b* (P<0.0001) color space values were the highest and the external pink color scores were the lowest (P<0.0001) in the 65.6°C cooked patties. Patties cooked to 71.1°C and 76.7°C did not differ in CIE L* and a* color space values and external pink color. The 71.1°C cooked patties were the least yellow compared to patties cooked to the other internal cook temperatures.

Internal cook temperature and meat type interactions were significant (P<0.05) for CIE L*, a*, and b* color space values (Figure 12) and for external pink color (Figure 13). Ground beef patties from high pH meat and MN meat had a reduction in L* values from 65.6°C to 71.1°C. High pH ground beef patties did not change in color attributes when cooked to 71.1°C and 76.7°C. The MN patties increased in L* color space values

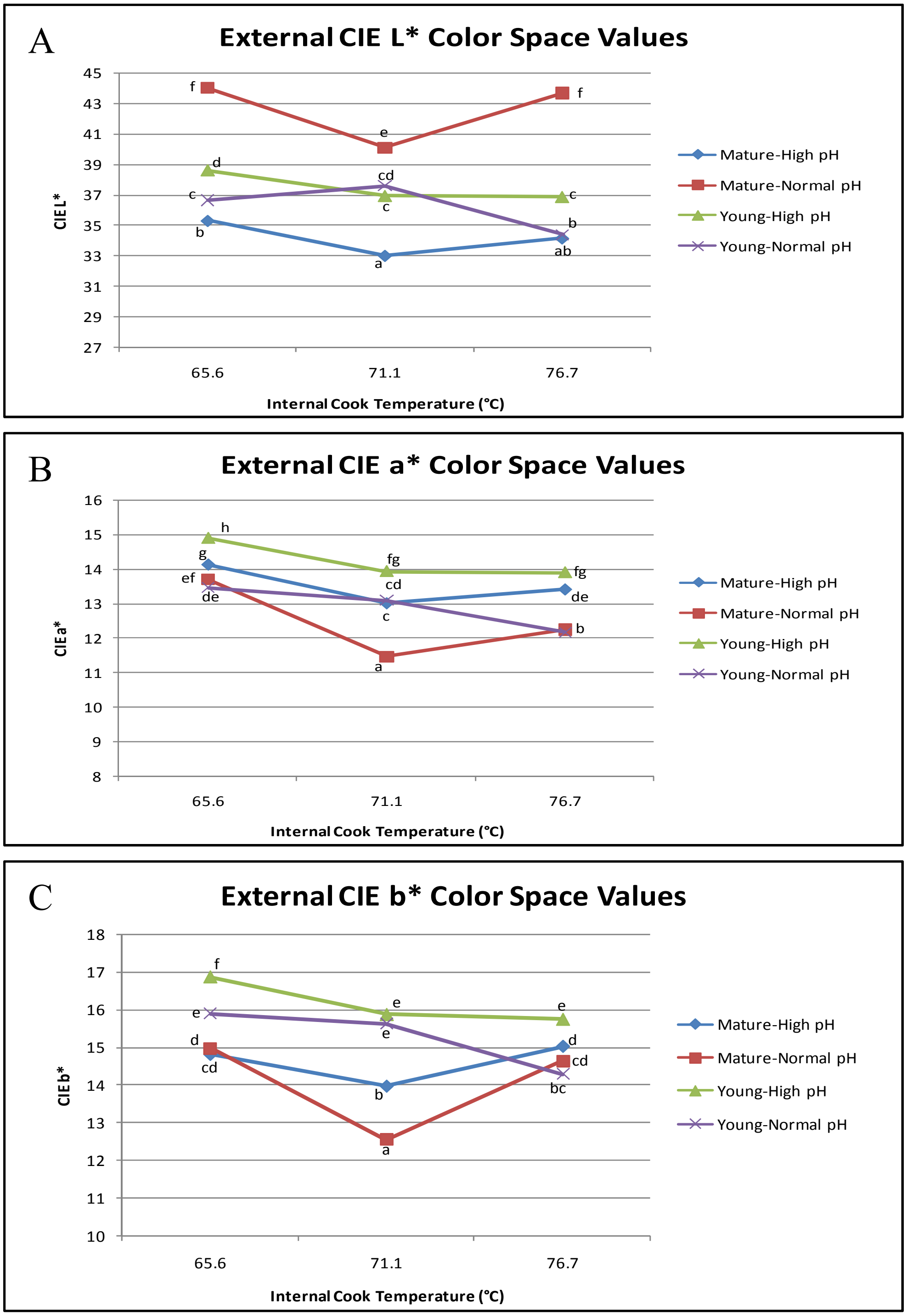

Figure 12. Least squares means for meat type and internal cook temperature interactions for external CIE (A) L* (*P*<0.0001[i]), (B) a* (*P*<0.0001[i]), and (C) b* (*P*<0.0001[i]) color space values.

[a-h]Mean values followed by the same letter are not significantly different (*P>0.05*).
[i]*P*-value from analysis of variance tables.

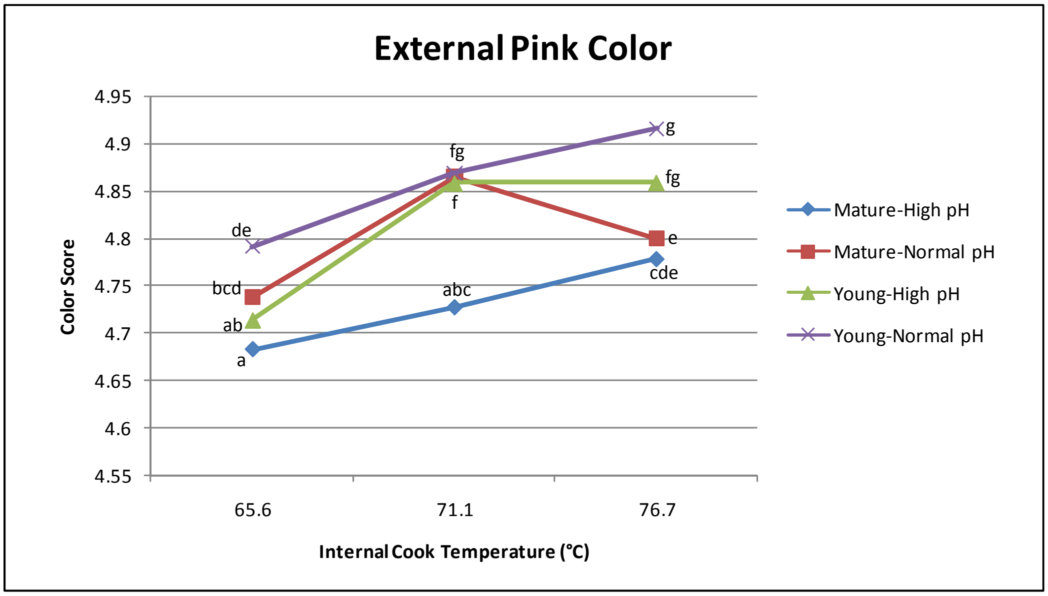

Figure 13. Least squares means for meat type and internal cook temperature interaction for external pink color[h] (P=0.0152[i]).

[a-g]Mean values followed by the same letter are not significantly different ($P>0.05$).
[h]External Pink Color: 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink.
[i]*P*-value from analysis of variance tables.

when cooked from 71.1°C to 76.7°C. There was no change in L* color space values in YN patties when they were cooked to 65.6°C or 71.1°C, but YN patties were darker when cooked to 76.7°C compared to those cooked to 71.1°C. The external color of normal pH patties was the least red when cooked to 65.6°C; YH patties were the reddest. A decrease in redness was reported as cook temperature increased from 65.6°C to 71.1°C for the high pH meat. High pH patties did not differ in redness when patties were cooked from 71.1°C to 76.7°C. The YN patties had similar redness when cooked to 65.6°C and 71.1°C and redness decreased in these patties when cooked to 76.7°C. Patties made from MN meat decreased in redness when cooked from 65.6°C to 71.1°C, while a* color space values increased in a* values when patties were cooked from 71.1°C to 76.7°C to those similar to the values at 65.6°C. The b* color space values decreased in YH, MN, and MH patties when cooked from 65.6°C to 71.1°C. The highest b* color space values were observed at all temperatures in the YH meat. External pink color scores for YN and MH ground beef patties increased with increasing internal cook temperatures indicating less pink color with cooking temperature increases. For YH and MN meat patties, an increase in external pink color scores occurred from 65.6°C to 71.1°C. External pink color scores did not differ from 71.1°C to 76.7°C for YH patties. A decrease in color scores was reported for MH patties at 76.7°C indicating a more pink appearance with the higher cook temperature. The greatest pink color was found in the MH patties regardless of internal cook temperature and YN patties were the least pink. YH and MN were similar in pinkness at the low internal cook temperature and as temperature increased to 71.1°C, there was no difference between these and the

YN patties. At the highest internal cook temperatures, patties with high myoglobin content (MN and MH) had similar external pink color and appeared less pink than the young patties or those with a lower myoglobin concentration.

Cooking method and internal cook temperature interactions were significant ($P<0.05$) for CIE L*, a*, and b* color space values (Figure 14) and for external pink color (Figure 15). The L* color space values for external color were always higher for moist cooked patties, regardless of cook temperature, compared to dry cooked patties. Dry cooked patties had decreasing L* color space values with increasing cook temperature, indicating a darkening of the surface. Moist cooked patties darkened from 65.6°C to 71.1°C but there was an increase in L* color space values at the highest cook temperature. External CIE a* color space values for dry cooked patties decreased with an increasing internal cook temperature. External a* color space values of ground beef patties decreased with the increase in cook temperature from 65.6°C to 71.1°C; moist cooked patties were less red at these temperatures than dry cooked. At 76.7°C, moist and dry cooked patties did not differ in external a* color space values. Dry cooked patties had lower b* values than the moist cooked ground beef patties with the exception of 71.1°C cooked patties which did not differ. All patties decreased in yellowness, b*, from 65.6°C to 71.1°C. Moist cooked patties had similar b* color space values at 71.1°C and 76.7°C; dry cooked patties increased in yellowness, b*, from 71.1°C to 76.7°C. The external pink color scores of dry cooked patties decreased with increasing internal cook temperature indicating a more done appearance. In contrast, the external

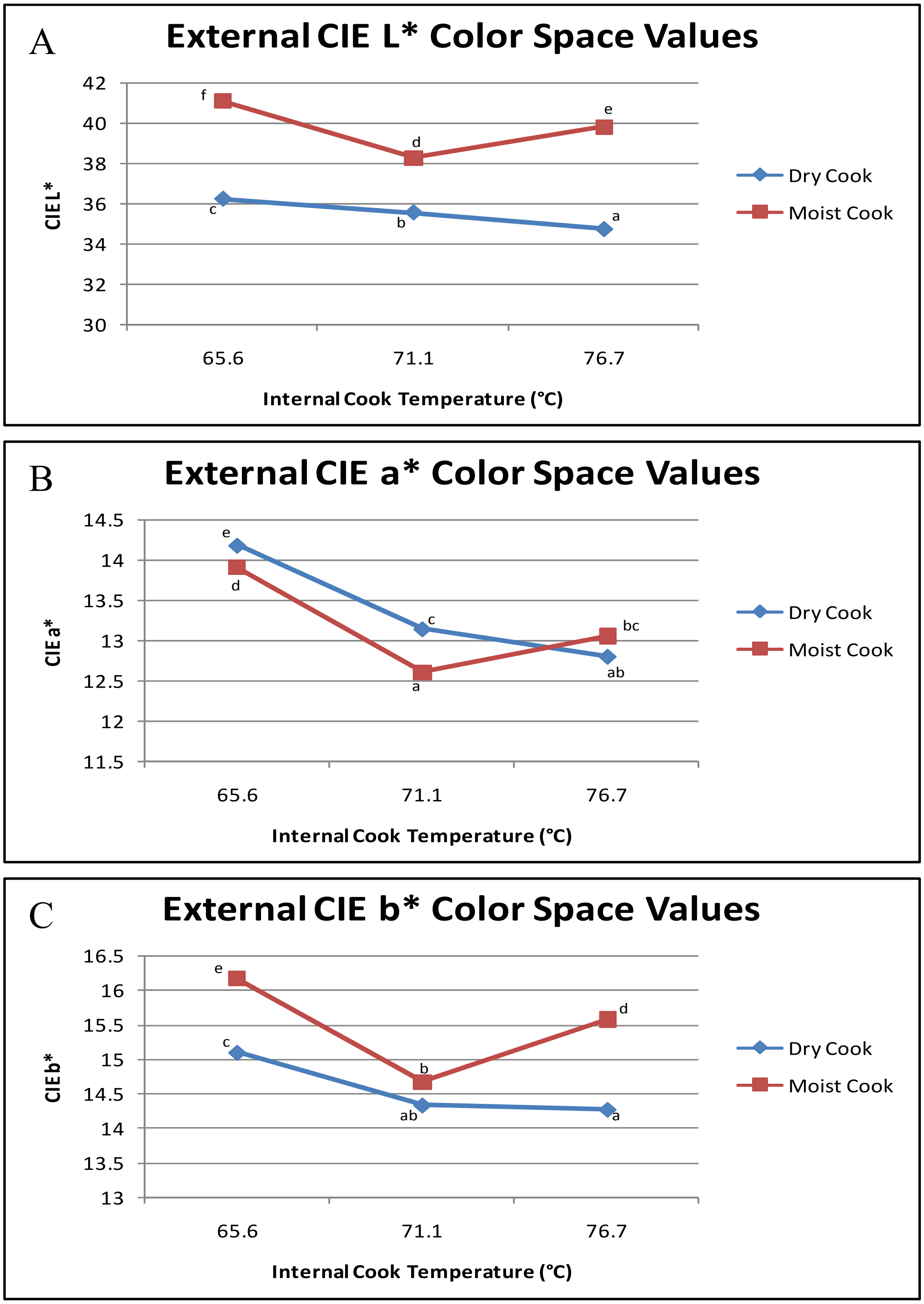

Figure 14. Least squares means for cooking method and internal cook temperature interactions for external CIE (A) L* (P<0.0001[g]), (B) a* (P=0.0002[g]), and (C) b* (P=0.0004[g]) color space values.

[a-f]Mean values followed by the same letter are not significantly different (P>0.05).
[g]P-value from analysis of variance tables.

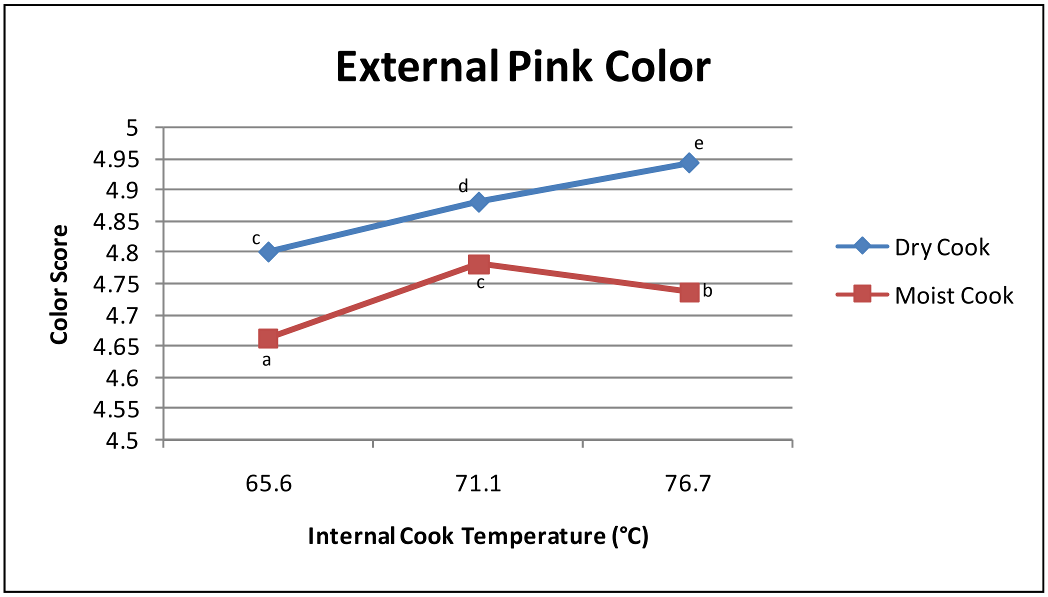

Figure 15. Least squares means for cooking method and internal cook temperature interaction for external pink color[f] (*P*=0.0007[g]).

[a-e]Mean values followed by the same letter are not significantly different (*P*>*0.05*).
[f]External Pink Color: 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink.
[g]*P*-value from analysis of variance tables.

pink color scores increased from 65.6°C to 71.1°C then decreased from 71.1°C to 76.7°C, indicating a reemergence of the red color at the highest cook temperature. This is probably due to the darkening of the patties in the dry cooking which masked the red external color. Moist cooked patties always appeared pinker externally and had lower scores, than the dry cooked patties.

Besides meat type, the internal cook temperature of the ground beef patties provided the greatest influence on cooked color development during the cooking process. Patties cooked in a moist environment had less color changes as internal cook temperature increased whereas patties cooked in a dry method decreased in colors associated with redness. The most unexpected effect of internal temperature was a plateau in doneness of patties at 71.1°C which was seen in patties of all meat sources.

Holding Method

Dry and moist holding methods were used to emulate procedures in foodservice establishments particularly when large amounts of food are prepared prior to a rush service time. Cook yield was higher for the patties held in the moist environment than the dry method (Table 2) (P<0.0001). Less moisture evaporation would be expected in patties from the moist holding environment than the dry holding treatment.

Internal color values differed (P<0.05) for CIE a* and b* color space values and degree of doneness due to holding method (Table 3). Moist held patties had higher a* and b* values and lower internal degree of doneness than dry held patties. There was no difference in CIE L* color space values (P=0.7461) and percentage of denatured myoglobin (*P*=0.3018) for holding method applied. There is very little data regarding the effects of hot holding on cooked meat color. One study reported that patties that were hot held had higher doneness scores compared to patties that were not held (Berry and Liu 1998).

An interaction for meat type and holding method was significant (*P*<0.05) for internal CIE a* color space values (Figure 16). The dry held patties were less red than moist patties within each meat type. The MH ground beef patties were the most red, had the highest a* value, and the YN patties were the least red and had the lowest a* internal color space values. Mancini and others (2005) reported color reemergence (increase a* values up to 48 hrs of storage) when evaluating the effect of cold storage after cooking. They reported that the reemergence was most pronounced when the ground beef patties were formed from high pH meat and cooked to lower internal cook temperatures.

A cooking method and holding method interaction was significant (*P*<0.05) for internal degree of doneness (Figure 17). Dry held patties of both cooking methods had similar degrees of doneness and were more done in appearance than the moist held patties. Dry cooked and moist held patties had the lowest doneness scores.

The external CIE L* and b* color space values were higher in the moist held patties than the dry held patties (*P*<0.0001) (Table 4). The CIE a* color space values (*P*=0.3784) and the external pink color (*P*=0.0805) did not differ due to holding method. It was hypothesized that the dry held patties would be darker due to the caramelizing and/or Maillard reaction on the surface. This did not occur on the surface of the moist held patties because no drying happened superficially.

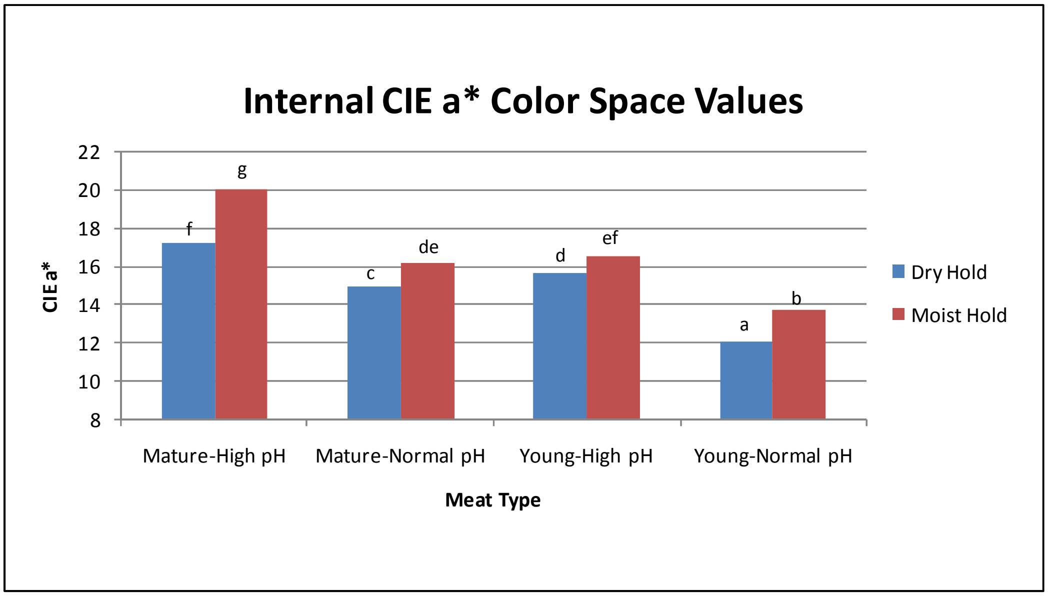

Figure 16. Least squares means for meat type and holding method interaction for internal CIE a* (P=0.0007[h]).

[a-g]Mean values followed by the same letter are not significantly different (P>0.05).
[h]P-value from analysis of variance tables.

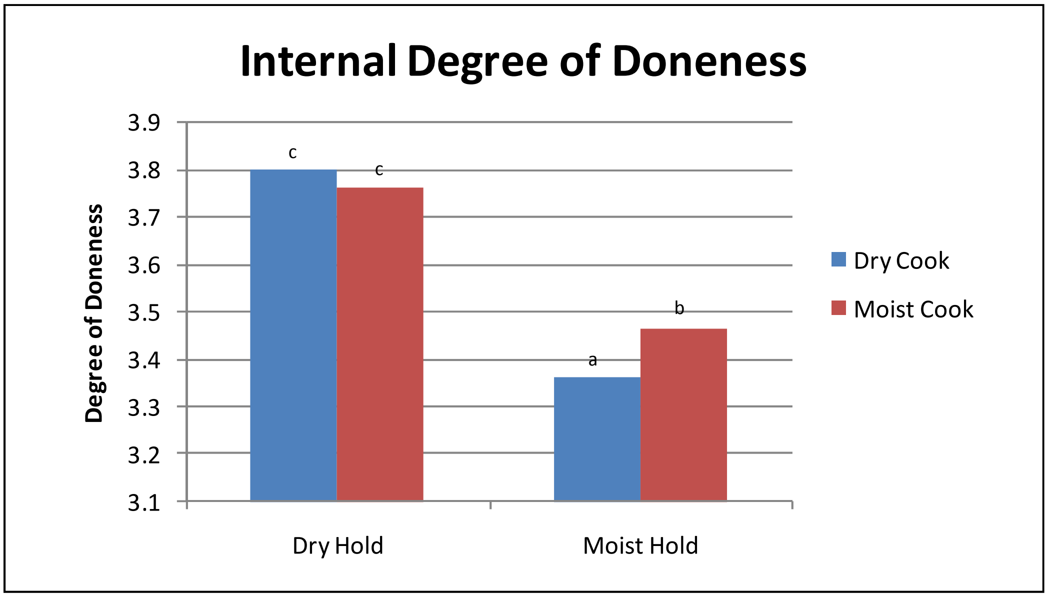

Figure 17. Least squares means for cooking method and holding method interaction for internal degree of doneness[d] (P=0.0315[e]).

[a-c]Mean values followed by the same letter are not significantly different ($P>0.05$).
[d]Internal Degree of Doneness: 1 = raw red center, pink border, tan edge (medium rare); 2 = reddish-pink center, pink border, tan edge; 3 = slightly pink center, light brown to tan edge (medium); 4 = tan/brown center and edges, no evidence of pink (well done); 5 = dry, brown throughout (very well done).
[e]*P*-value from analysis of variance tables.

Significant interactions ($P<0.05$) were present for meat type and holding method for external CIE L*, a*, and b* color space values (Figure 18) and for external pink color (Figure 19). External CIE L* and b* color space values were higher in the dry holding environment than the moist holding within each meat type. The CIE a* color space values did not differ due to holding method in the MH patties. The MN patties were the least red in the dry holding environment and patties made from normal pH meat sources were the least red in moist holding. There were higher external pink color scores for MH and YN meat in the dry holding environment than those patties in the moist holding. The MN patties had lower color scores for moist cooking than those scores in the dry holding method. In the YH patties, no differences for external pink color were observed between the holding methods applied.

Cooking method and holding method interactions were significant ($P<0.05$) for external CIE a* and b* color space values (Figure 20). The least red, lowest a* patties were observed in the moist cooking and moist holding treatment combination. When patties were switched from dry cook to moist hold or moist cook to dry hold the resultant patties were the most red and had the highest a* color space values. The most yellow patties were from moist holding regardless of the cooking method. Patties did not differ in b* color space values cooking and holding methods. Dry cooking with dry holding resulted in the least yellow patties. A masking of the yellowness in the dry holding, where the exteriors of the patties were much darker, most likely explains this effect. An unexpected result was observed when redness was not reduced in the dry holding as much as the yellowness.

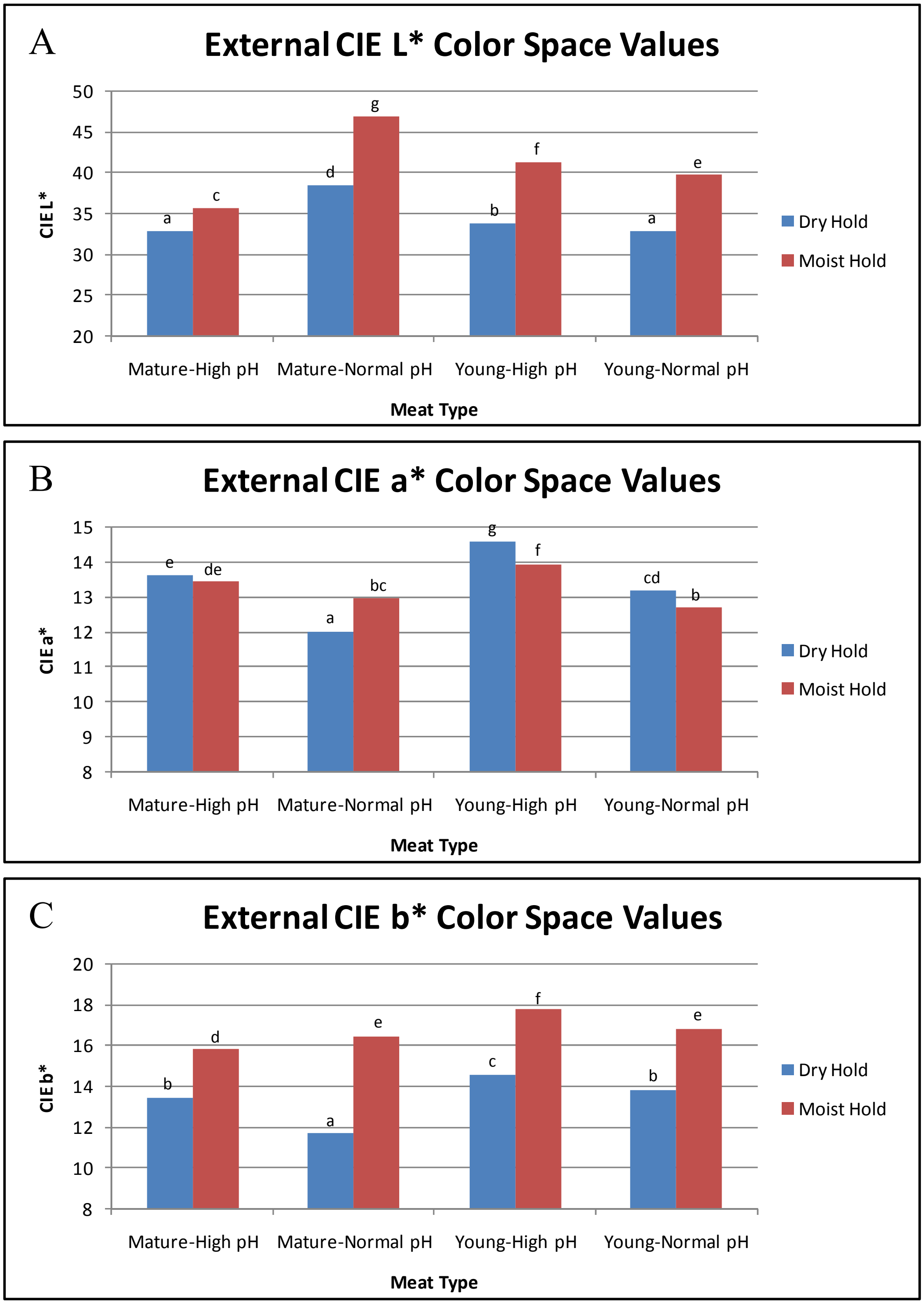

Figure 18. Least squares means for meat type and holding method interactions for external CIE (A) L* (*P*<0.0001[h]), (B) a* (*P*<0.0001[h]), and (C) b* (*P*<0.0001[h]) color space values.

[a-g]Mean values followed by the same letter are not significantly different (*P>0.05*).
[h]*P*-value from analysis of variance tables.

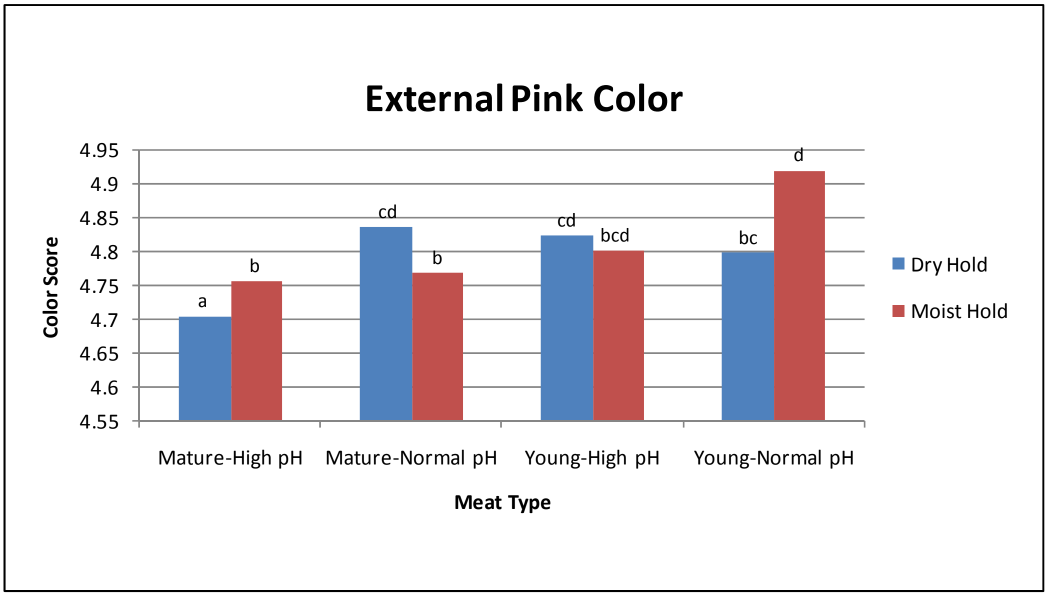

Figure 19. Least squares means for meat type and holding method interaction for external pink color[e] (P<0.0001[f]).

[a-d]Mean values followed by the same letter are not significantly different (P>0.05).
[e]External Pink Color: 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink.
[f]P-value from analysis of variance tables.

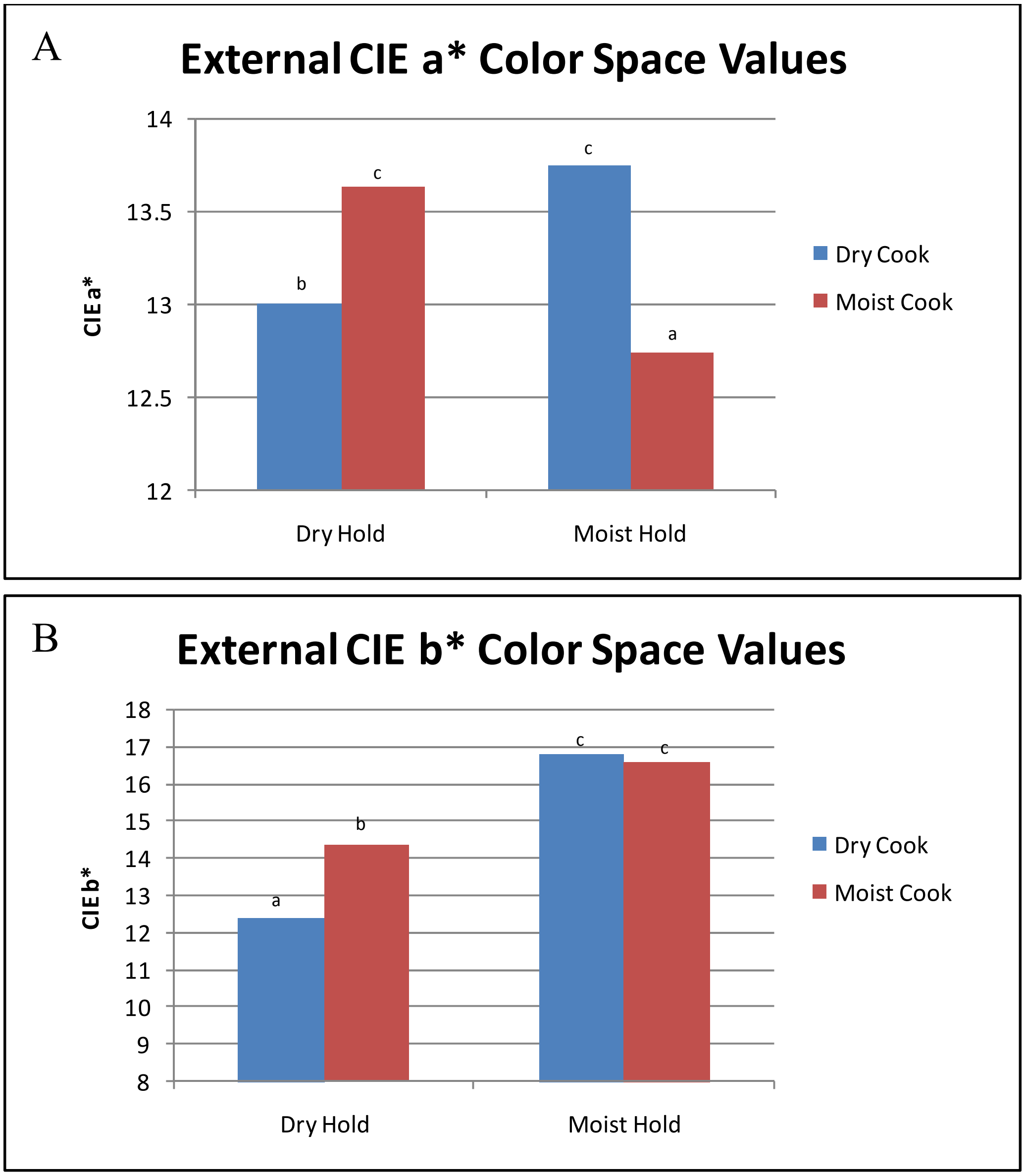

Figure 20. Least squares means for cooking method and holding method interactions for external CIE (A) a* (P<0.0001[e]) and (B) b* (P<0.0001[e]) color space values.

[a-d]Mean values followed by the same letter are not significantly different (P>*0.05*).
[e]P-value from analysis of variance tables.

Internal cook temperature and holding method interactions were significant ($P<0.05$) for external CIE a* and b* color space values (Figure 21). At 65.6°C, the a* color space values were lower for the moist holding than the dry holding method. No difference was observed at 71.1°C or 76.7°C for a* color space values for the two holding methods. The highest a* color space values were seen in the patties cooked to 65.6°C and moist held. External b* values were higher in patties in moist holding regardless of the internal cook temperatures. The lowest b* color space values were found in patties that were cooked to 71.1°C and dry held.

These results indicate that holding method affected color development in ground beef patties from differing meat sources. In contrast to cooking method, the holding of ground beef patties in a dry environment produced more done patty appearance both internally and externally compared to cooking with moisture.

Holding Time

As expected, holding of ground beef patties in a hot environment affected the cook yield and the internal and external color attributes. Cook yield was highest in patties that were not held (Table 2) ($P<0.0001$). Berry (1998) reported a reduction in yield for patties that were cooked to 71°C and held for 90 min at 63°C compared to those cooked to 71°C alone.

An interaction was significant ($P<0.05$) for cook yield for meat type and holding time (Figure 22). Difference in cook yield was apparent at 0 minutes of hold time (or directly after cooking) due to the different meat types. As hold time increased the patties

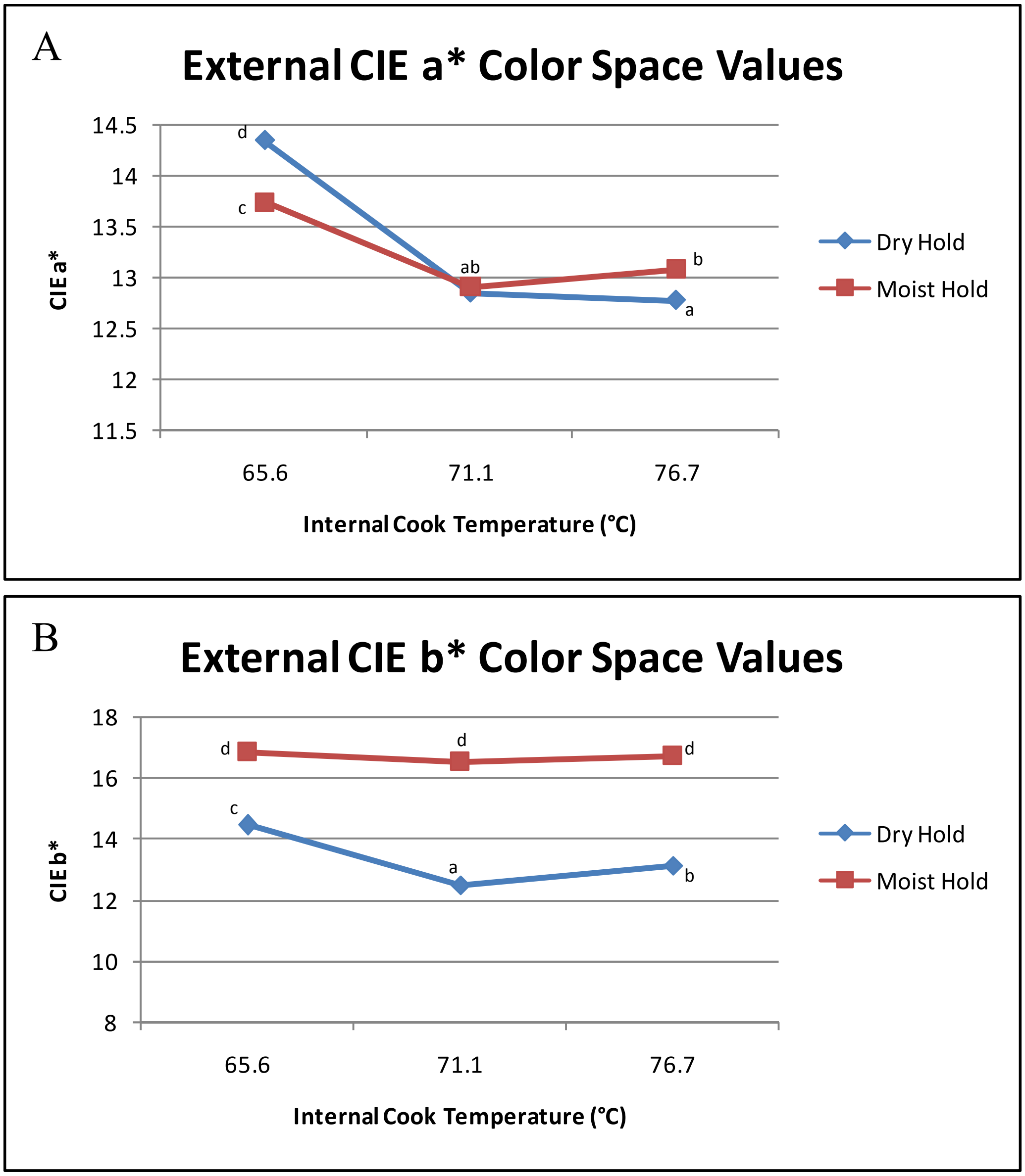

Figure 21. Least squares means for internal cook temperature and holding method interactions for external CIE (A) a* (P<0.0001[e]) and (B) b* (P<0.0001[e]) color space values.

[a-d]Mean values followed by the same letter are not significantly different (P>0.05).
[e]P-value from analysis of variance tables.

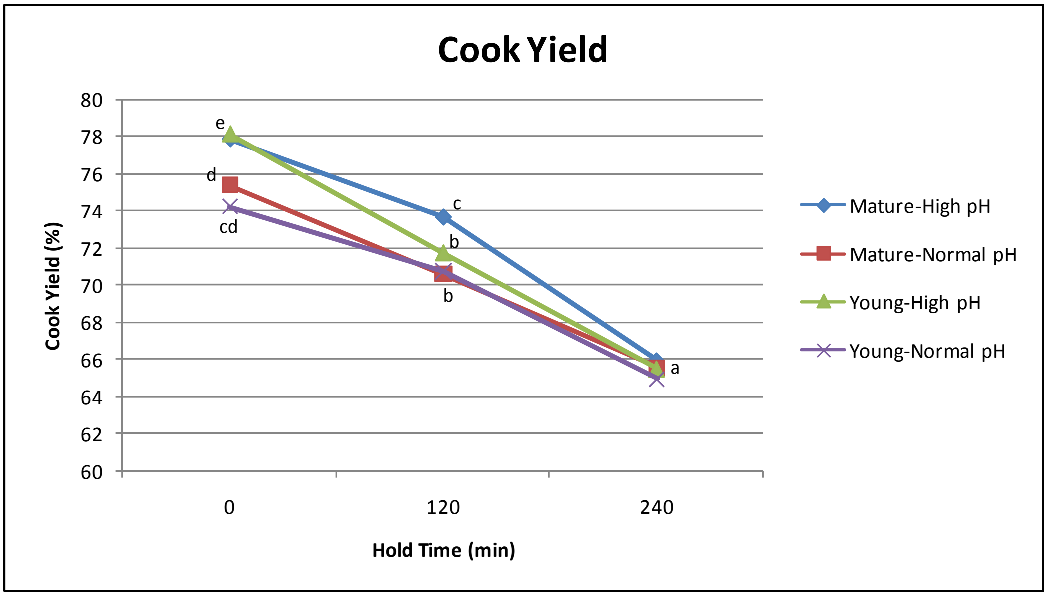

Figure 22. Least squares means for meat type and holding time interaction for cook yield[f] (*P*=0.0002[g]).

[a-e]Mean values followed by the same letter are not significantly different (*P>0.05*).
[f]Cook yield = (cook weight/raw weight) × 100.
[g]*P*-value from analysis of variance tables.

from mature meat sources had the highest cook yield at 120 minutes. Holding for 240 minutes resulted in similar cook yields between all meat types.

Internal cook temperature and holding time had a significant (*P*<0.05) interaction for cook yield (Figure 23). There was a decrease in cook yield as holding increased for all three cook temperatures. Cook yield was highest for patties cooked to 65.6°C at all hold times. The cook yield did not differ in patties that were cooked to 71.1°C and 76.7°C over the duration of holding.

A holding method and holding time interactions was significant (*P*<0.05) for cook yield (Figure 24). A decrease in cook yield was observed in patties held in both moist and dry environments. This decrease was more pronounced in patties held in the dry method. This is in contrast to what was observed for the cooking method, where the observed yield was lower in the patties in the moist method compared to the dry cooking method.

Internal cooked color attributes and percent of denatured myoglobin differed between hold times (*P*<0.0001) (Table 3). The L* color space values were higher with 120 and 240 min of holding compared to no holding. The CIE a* and b* color space values and degree of doneness scores did not differ at 0 and 120 min of holding and were lower with the longer holding time of 240 min. Myoglobin denaturation was highest at 240 min and lowest at 0 min of holding; it was not measured at 120 min. Though not a direct comparison, Ryan and others (2006) found that holding patties for 1-12 min after cooking increased the percentage of myoglobin denatured, increased doneness scores, and decreased a* values as compared with cooking and no holding time in ground beef

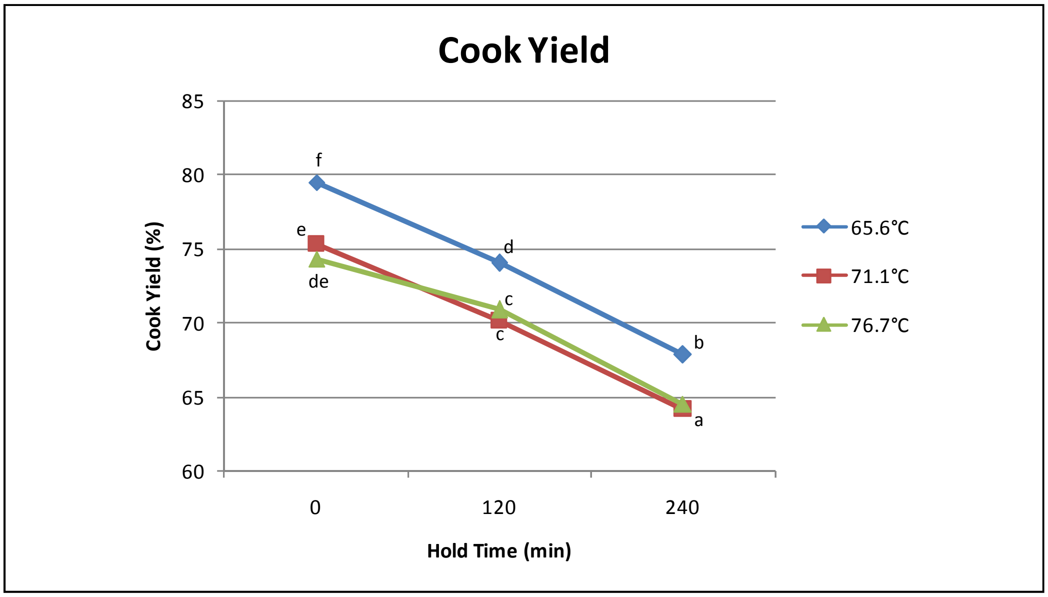

Figure 23. Least squares means for internal cook temperature and holding time interaction for cook yield[g] (P=0.047[h]).

[a-f]Mean values followed by the same letter are not significantly different ($P>0.05$).
[g]Cook yield = (cook weight/raw weight) × 100.
[h]P-value from analysis of variance tables.

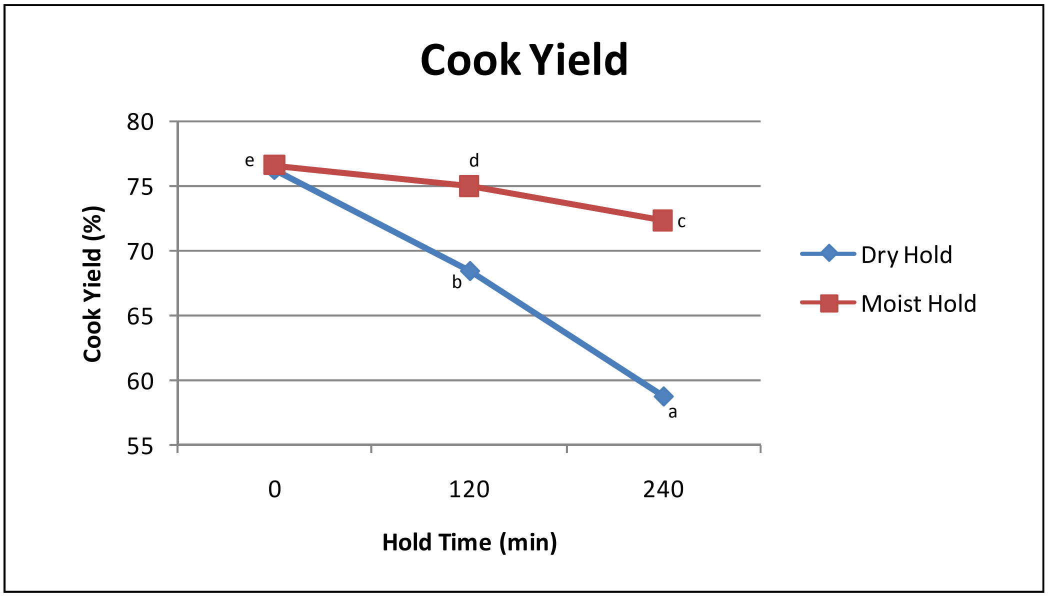

Figure 24. Least squares means for holding method and holding time interaction for cook yield[f] (*P*<0.0001[g]).

[a-e]Mean values followed by the same letter are not significantly different (*P>0.05*).
[f]Cook yield = (cook weight/raw weight) × 100.
[g]*P*-value from analysis of variance tables.

patties. Similarly, Berry and Bigner-George (2000) found that holding for 4.5 min increased L*, decreased a* and b* and increased brown color score in ground beef patties.

Internal CIE L*, a*, and b* color space values (Figure 25) and degree of doneness scores (Figure 26) had significant ($P<0.05$) interactions for meat type and holding time. There was no change in internal L* color space values for MN, YH, and YN patties with increasing hold time. There was an increase in the internal L* color space values, darkening, in MH patties with increasing hold time. The a* color space values decreased with an increase in hold time. The differences induced by meat type were not overcome with increase hold time, meaning that the redness of patties were still different at the end of holding, with the exception of YH and MN. Ground beef patties from YN always had the lowest a* color space values and MH patties always had the highest a* color space values. The MN and YH patties had similar redness (a*) at 120 and 240 minutes of hold time; at 0 min of holding, MN patties were less red than YH patties. There was an increase in doneness scores for high pH meat source patties with an increase in hold time. The YN patties had no apparent changes from 0 to 120 min and an increase in apparent doneness was observed at 240 min. Ground beef patties from MN meat had a decrease in degree of doneness at 120 minutes from 0 minutes but by 240, they were equal in doneness as the YH ground beef patties. This would be an example of how pink color reemergence could be overcome with an increase in hot holding time.

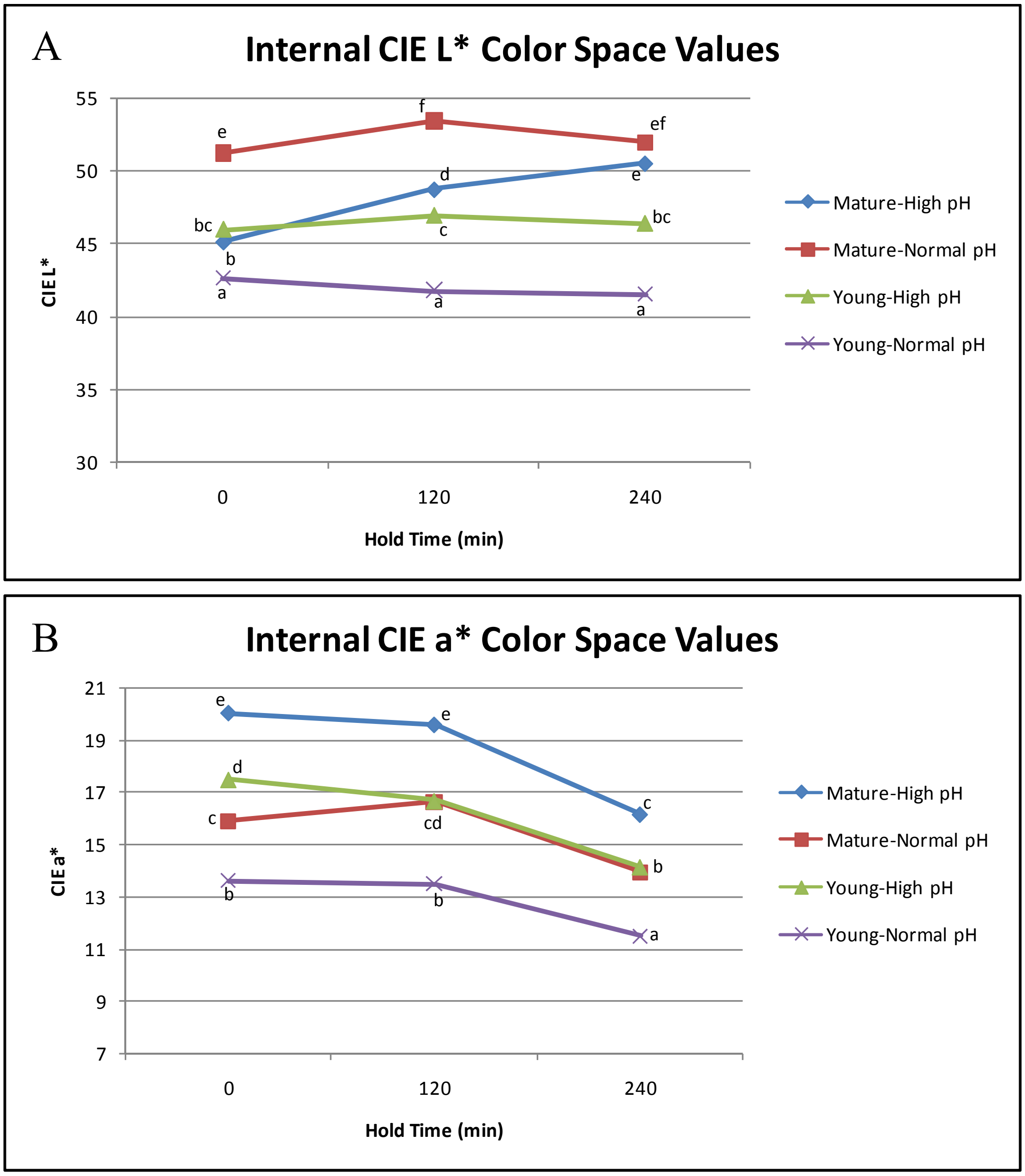

Figure 25. Least squares means for meat type and holding time interactions for internal CIE (A) L* (P<0.0001[h]) and (B) a* (P=0.0057[h]) color space values.

[a-g]Mean values followed by the same letter are not significantly different (P>0.05).
[h]P-value from analysis of variance tables.

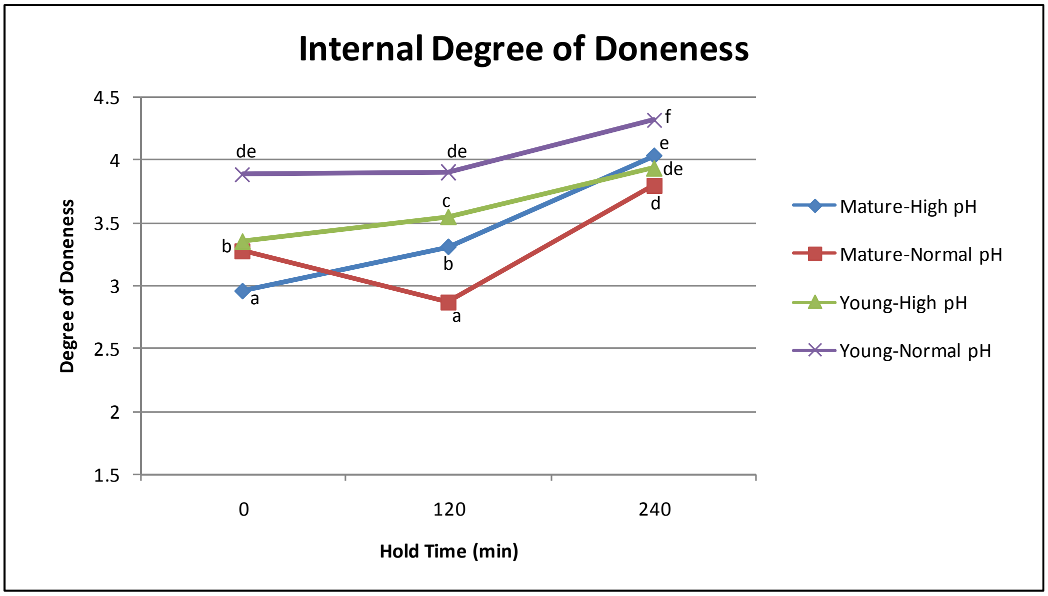

Figure 26. Least squares means for meat type and holding time interaction for internal degree of doneness[n] (P<0.0001[o]).

[a-m]Mean values followed by the same letter are not significantly different (P>*0.05*).
[n]Internal Degree of Doneness: 1 = raw red center, pink border, tan edge (medium rare); 2 = reddish-pink center, pink border, tan edge; 3 = slightly pink center, light brown to tan edge (medium); 4 = tan/brown center and edges, no evidence of pink (well done); 5 = dry, brown throughout (very well done).
[o]*P*-value from analysis of variance tables.

An internal cook temperature and holding time interaction was significant (*P*<0.05) for internal degree of doneness (Figure 27). Internal degree of doneness was higher for patties cooked to 71.1°C and 76.7°C except at 0 min of holding in which the 76.7°C ground beef patties had higher scores, appeared more done, than the 71.1°C cooked patties. Holding patties cooked to 65.6°C for 240 min resulted in degree of doneness scores that were equal to patties cooked to 71.1°C and 76.7°C that were held for shorter times, 0 and 120 min.

Interactions were significant (*P*<0.05) for holding method and holding time for internal CIE a* and b* color space values (Figure 28) and for internal degree of doneness (Figure 29). Dry held patties decreased in redness (a*) and yellowness (b*) throughout holding, as expected. Moist and dry held patties had the same values at 0 min which would be expected because half of each of the patties were from each cooking method. By the end of holding, dry held ground beef patties had much lower a* and b* color space values than moist held patties. The moist held patties did not differ in a* and b* color space values at 0 and 120 min and decreased at 240 min. The internal degree of doneness scores were similar for both moist and dry holding at 0 min. The dry held patties appeared more done, had higher doneness scores, than moist held patties at 120 and 240 min of holding. The degree of doneness scores increased in dry held patties over the entire holding time with the greatest increase from 120 to 240 min. The only observed difference in doneness scores for moist held patties was from 120 to 240 min; no difference was seen between 0 and 120 min held patties.

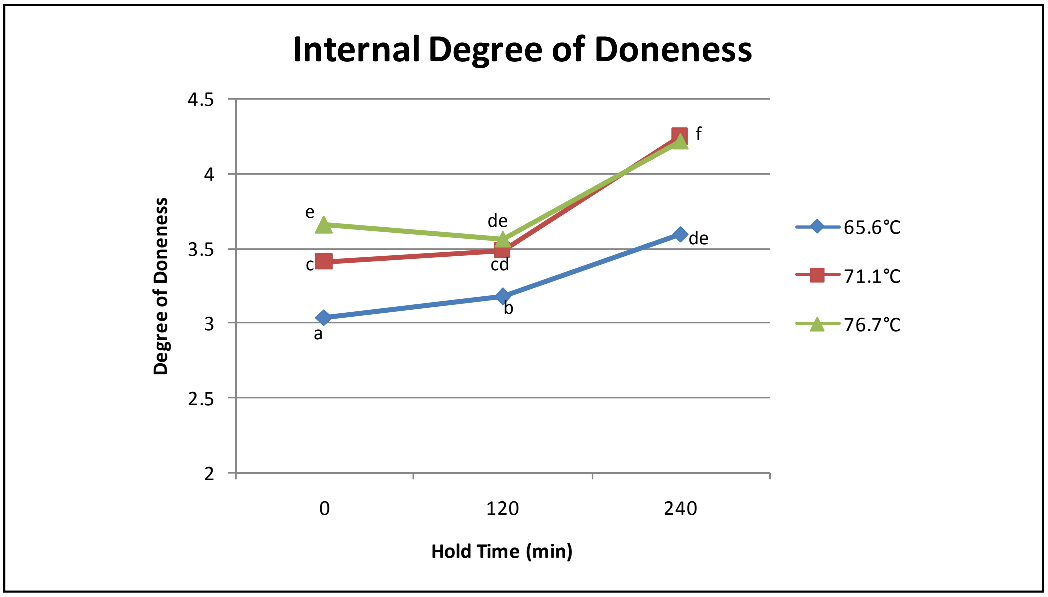

Figure 27. Least squares means for internal cook temperature and holding time interaction for internal degree of doneness[o] (P=0.0008[p]).

[a-n]Mean values followed by the same letter are not significantly different ($P>0.05$).
[o]Internal Degree of Doneness: 1 = raw red center, pink border, tan edge (medium rare); 2 = reddish-pink center, pink border, tan edge; 3 = slightly pink center, light brown to tan edge (medium); 4 = tan/brown center and edges, no evidence of pink (well done); 5 = dry, brown throughout (very well done).
[p]P-value from analysis of variance tables.

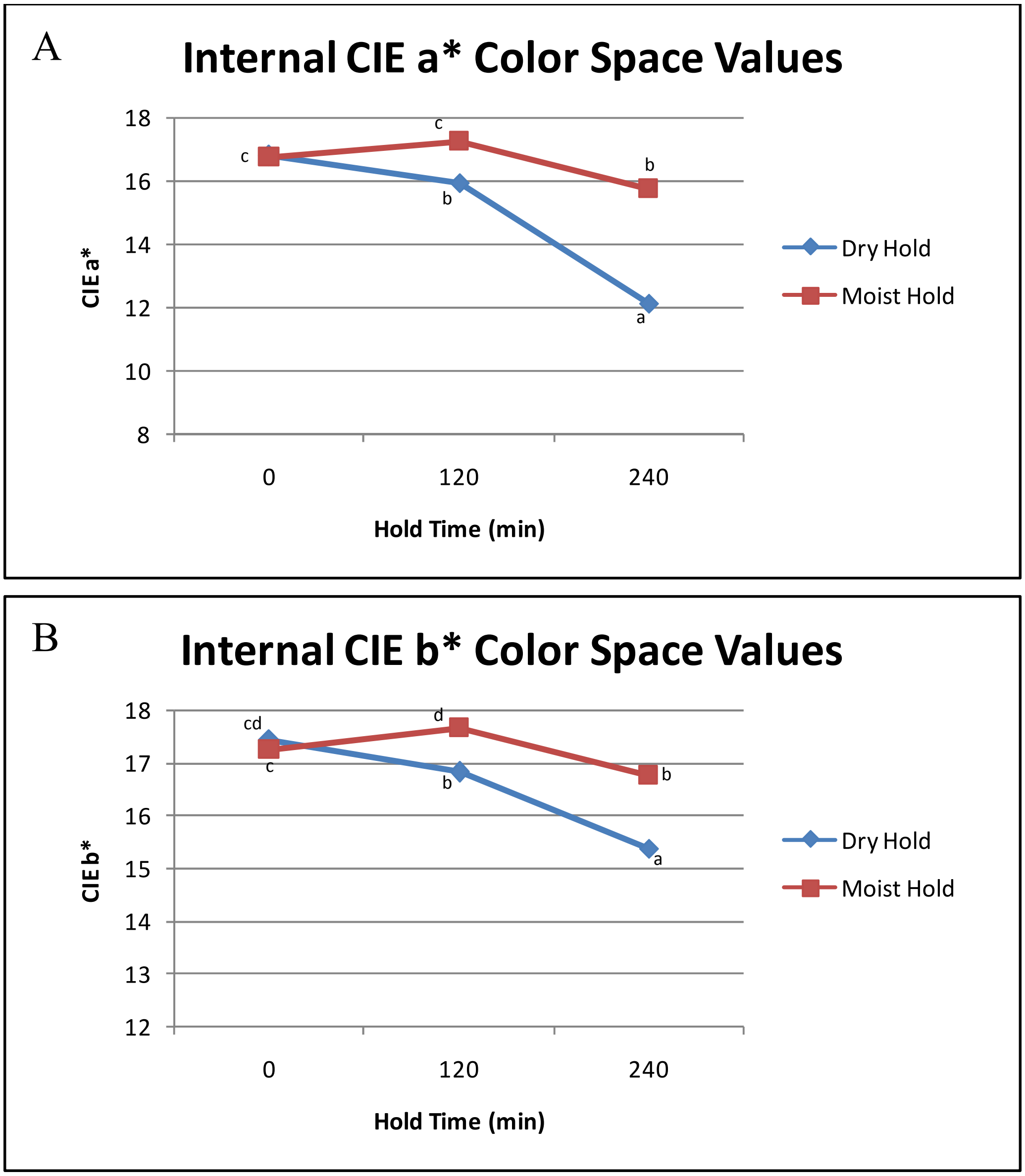

Figure 28. Least squares means for holding method and holding time interactions for internal CIE (A) a* (P<0.0001[e]) and (B) b* (P<0.0001[e]) color space values.

[a-d]Mean values followed by the same letter are not significantly different (P>0.05).
[e]P-value from analysis of variance tables.

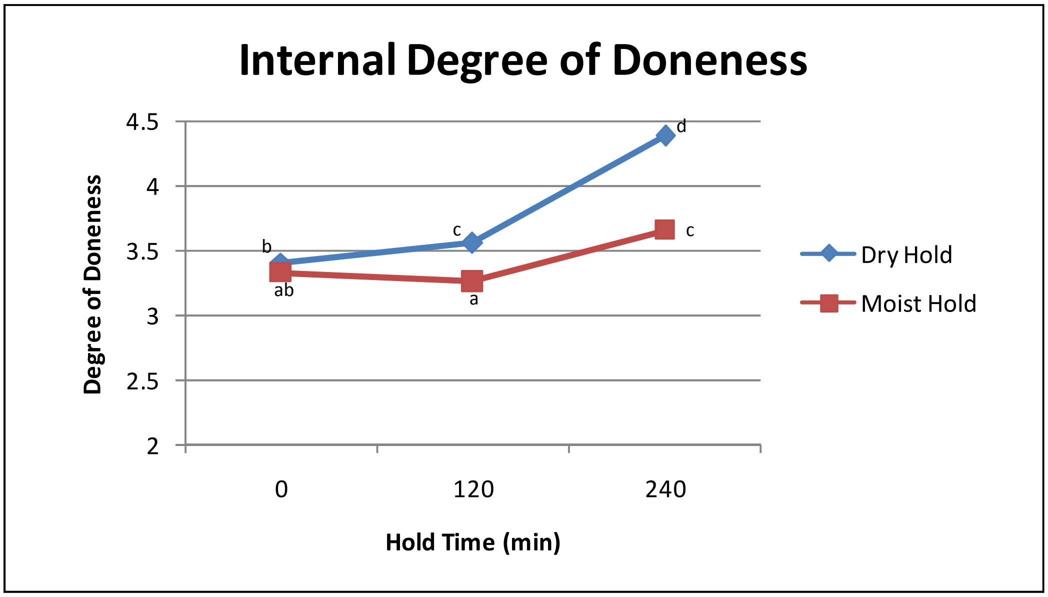

Figure 29. Least squares means for holding method and holding time interaction for internal degree of doneness[l] (*P*<0.0001[m]).

[a-k]Mean values followed by the same letter are not significantly different (*P>0.05*).
[l]Internal Degree of Doneness: 1 = raw red center, pink border, tan edge (medium rare); 2 = reddish-pink center, pink border, tan edge; 3 = slightly pink center, light brown to tan edge (medium); 4 = tan/brown center and edges, no evidence of pink (well done); 5 = dry, brown throughout (very well done).
[m]*P*-value from analysis of variance tables.

External CIE color space values and pink color scores differed due to holding time (*P*<0.0001) (Table 4). The L* color space values decreased with increasing holding time indicating that the patties darkened externally. There was no difference in the L* values at 60 and 90 min, 120 and 150 min, nor 180 and 210 min. The external redness of the ground beef patties decreased at each increasing holding time measured with the exception of 30 to 60 min and 120 to 150 min, which did not differ. The yellowness of the patties decreased with each 30 min increment of holding time from 0 to 240 min. The external pink color scores increased over the holding time indicating that there was a decrease in the external pinkness of the patties. These scores plateaued at 180 min as no difference was observed in the patties held to 180, 210, and 240 min. There was no difference in the external pink scores at 60, 90, and 150 min, nor was there a difference in the pink scores at 120 and 150 min.

Meat type and holding time interactions were significant (*P*<0.05) for external CIE L*, a*, and b* color space values (Figure 30) and external pink color (Figure 31). There was a decrease in external L*, a*, and b* values with increasing hold time. The high pH patties started (0 min of holding) with higher a* and b* color space values than did the normal pH patties. The patties made from young meat sources had higher a* and b* color space values than the mature meat source patties at 240 min of holding. The L* color space values of patties from different meat sources were different at the shorter holding times. The MN patties were always lighter (higher L*) than the MH, YH, or YN patties. The MN, YH, and YN patties were equal in external L* values at the end of holding (240 min). Generally, as hold time increased, there was a reduction in the

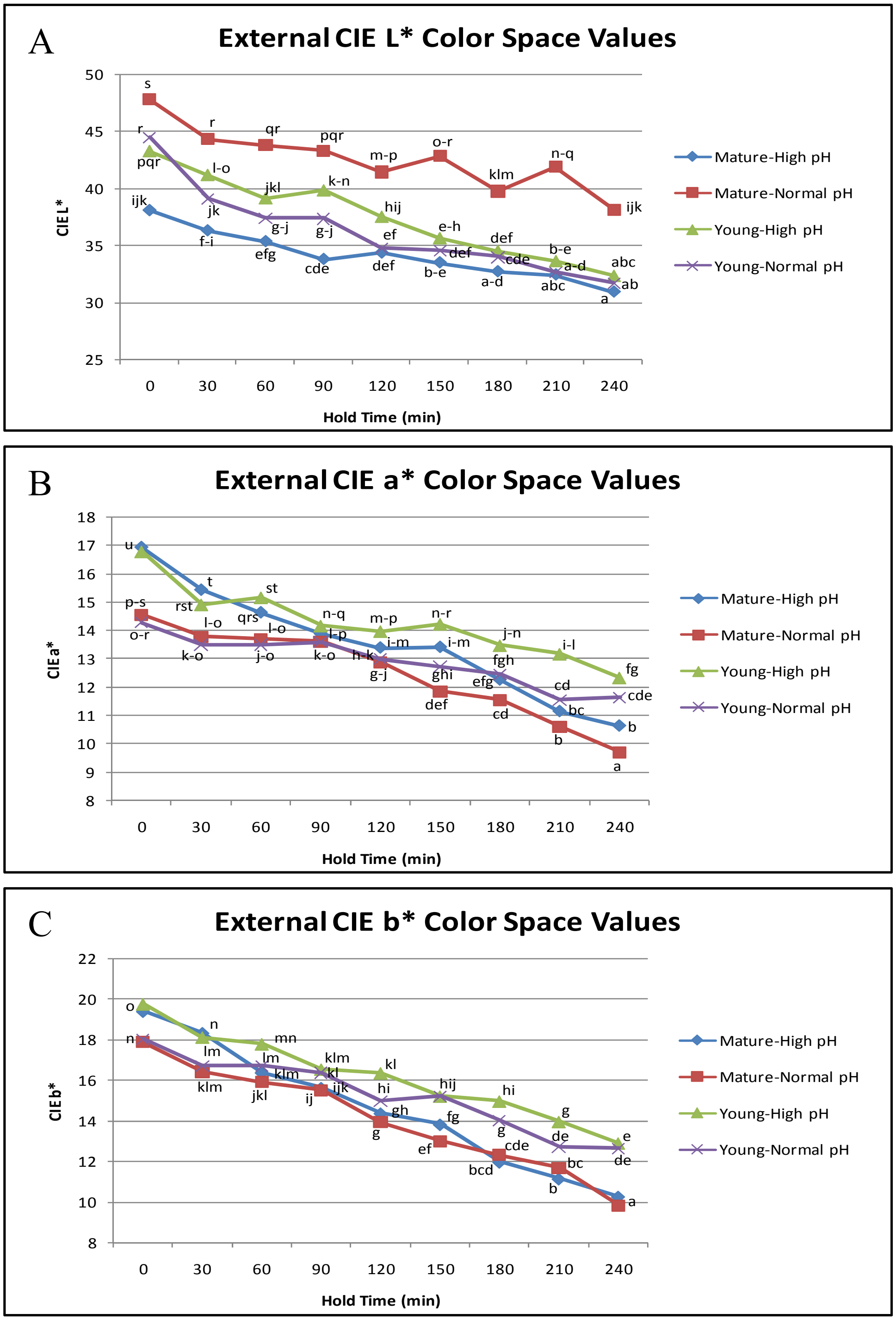

Figure 30. Least squares means for meat type and holding time interactions for external CIE (A) L* (P<0.0001[v]), (B) a* (P<0.0001[v]), and (C) b* (P<0.0001[v]) color space values.

[a-u]Mean values followed by the same letter are not significantly different (P>*0.05*).
[v]*P*-value from analysis of variance tables.

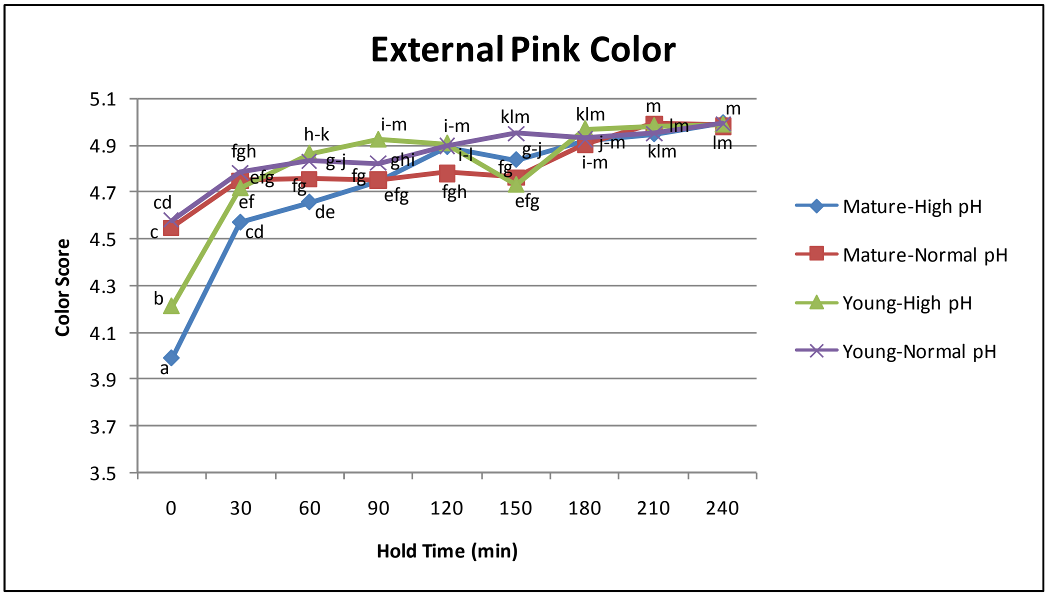

Figure 31. Least squares means for meat type and holding time interaction for external pink color[n] (P<0.0001[o]).

[a-m]Mean values followed by the same letter are not significantly different (P>0.05).
[n]External Pink Color: 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink.
[o]P-value from analysis of variance tables.

differences between meat types for external pink color. All meat types were similar in external pink color at 240 min of holding, indicating that hot holding reduces the external pink color differences induced by meat type.

Cooking method and holding time interactions were also significant (*P*<0.05) for external CIE L*, a*, and b* color space values (Figure 32) and external pink color (Figure 33). External color values decreased with increasing hold time for patties from both cooking methods. With the exception of L* color space values, dry cooking had higher values than moist cooking at 0 and 30 min. The b* color space values at 90 min and the a* color space values at 180 min were lower in dry cooking than those observed in moist cooking; this was observed for a* and b* values at subsequent times. The L* color space values were always higher in patties that were moist cooked than patties that were dry cooked. This was expected because there was little to no caramel color development (darkening which would mask the redness and/or yellowness) on the exterior of the moist cooked patties even with the extended hold time. The moist cooked patties had lower external pink color than the patties in the dry cooking for 0 and 60 through 150 min. The external pink color scores increased during these times indicating a decrease in the amount of pink present on the surface of the patties. There was no effect of cooking method on the external pink color of patties that were held 30, 180, 210, and 240 min.

Interactions were significant (*P*<0.05) for internal cooked temperature and holding time for external CIE a* and b* color space values (Figure 34) and external pink color (Figure 35). The CIE a* and b* values decreased over hold time within each cook

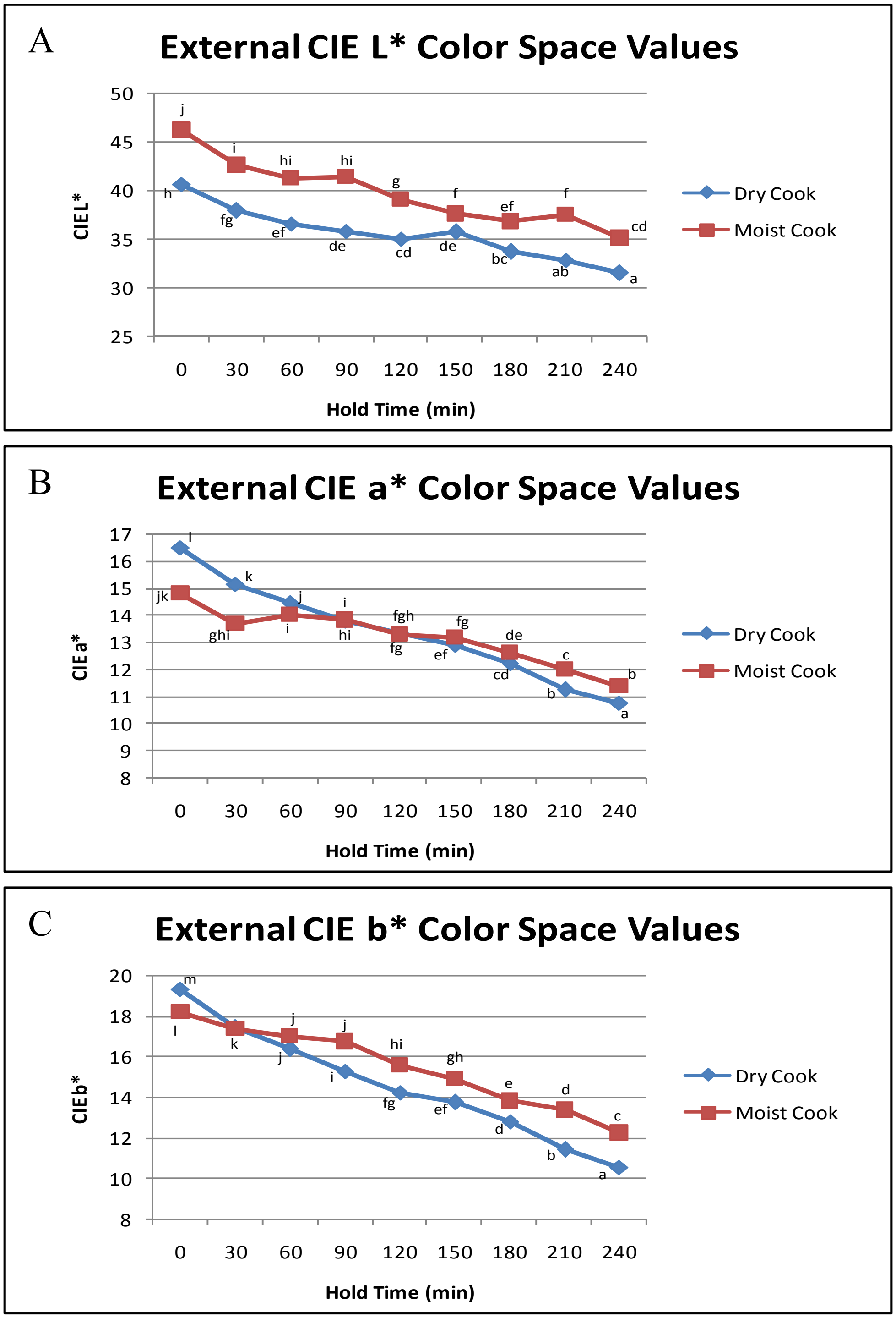

Figure 32. Least squares means for cooking method and holding time interactions for external CIE (A) L* (P=0.0121[n]), (B) a* (P<0.0001[n]), and (C) b* (P<0.0001[n]) color space values.

[a-m]Mean values followed by the same letter are not significantly different (P >0.05).
[n]P-value from analysis of variance tables.

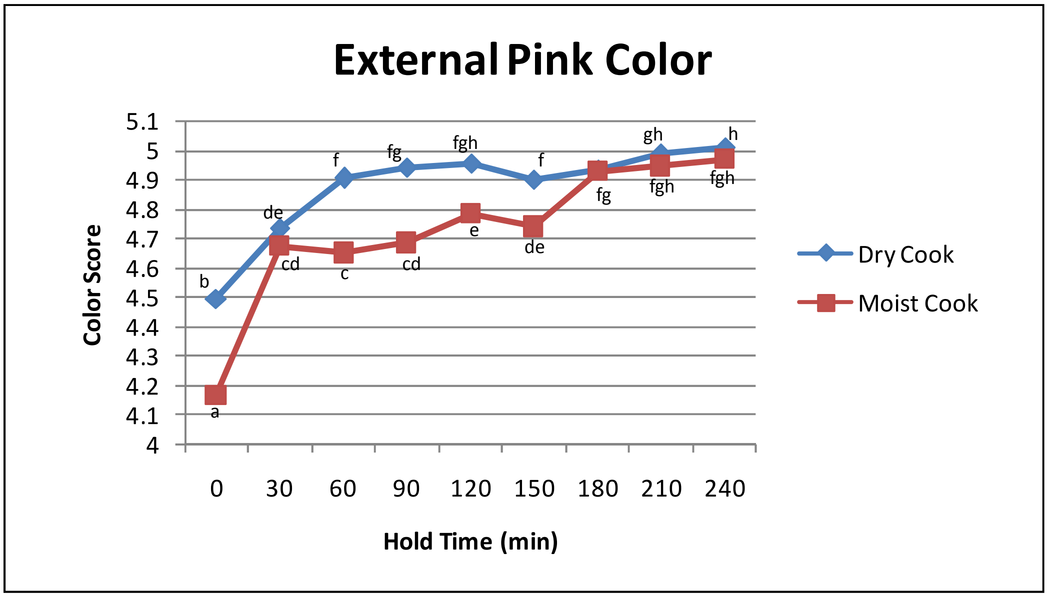

Figure 33. Least squares means for cooking method and holding time interaction for external pink color[i] (P<0.0001[j]).

[a-h]Mean values followed by the same letter are not significantly different ($P>0.05$).
[i]External Pink Color: 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink.
[j]P-value from analysis of variance tables.

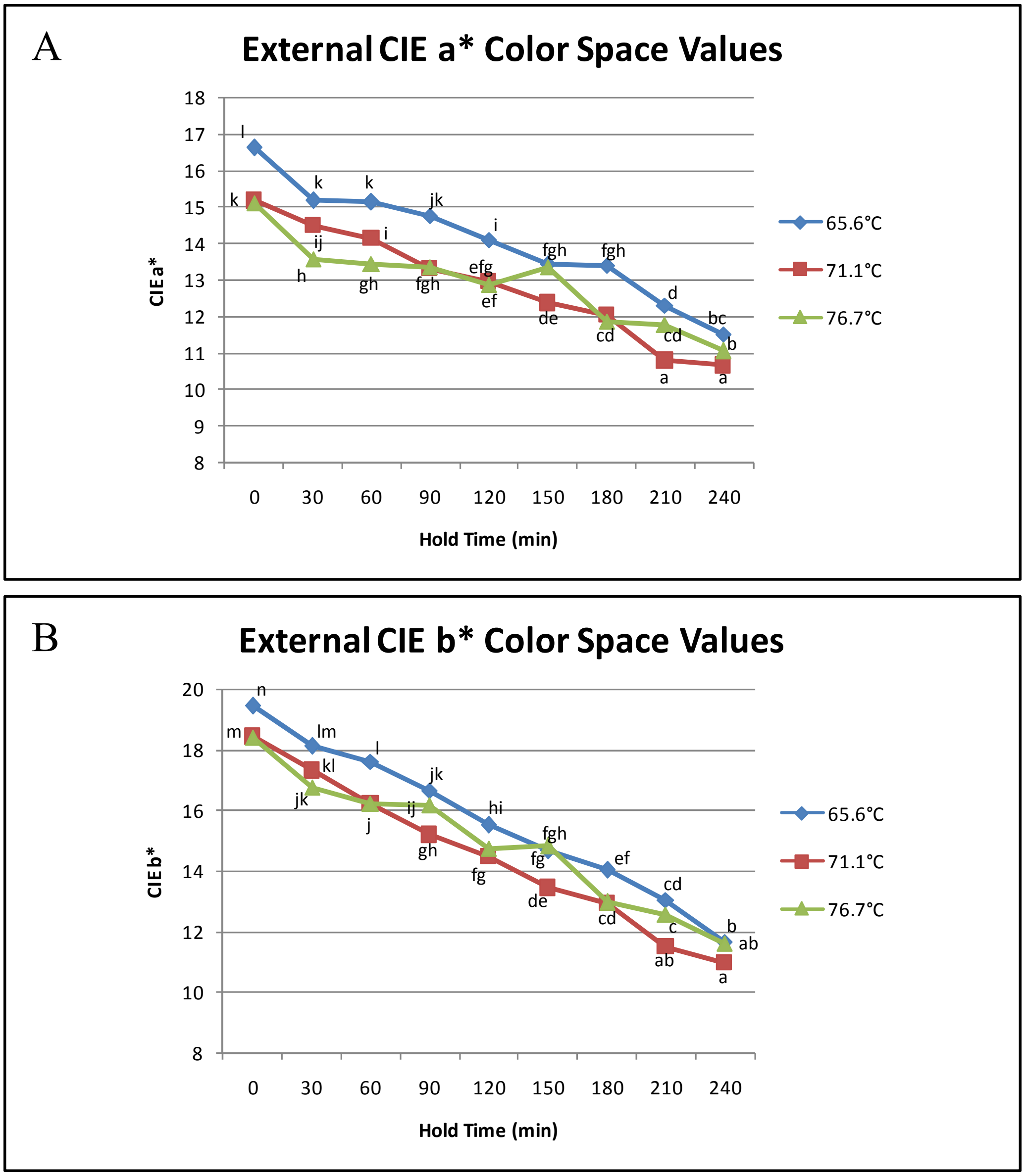

Figure 34. Least squares means for internal cook temperature and holding time interactions for external CIE (A) a* (P<0.0001°) and (B) b* (P=0.0371°) color space values.

[a-n]Mean values followed by the same letter are not significantly different ($P>0.05$).
°P-value from analysis of variance tables.

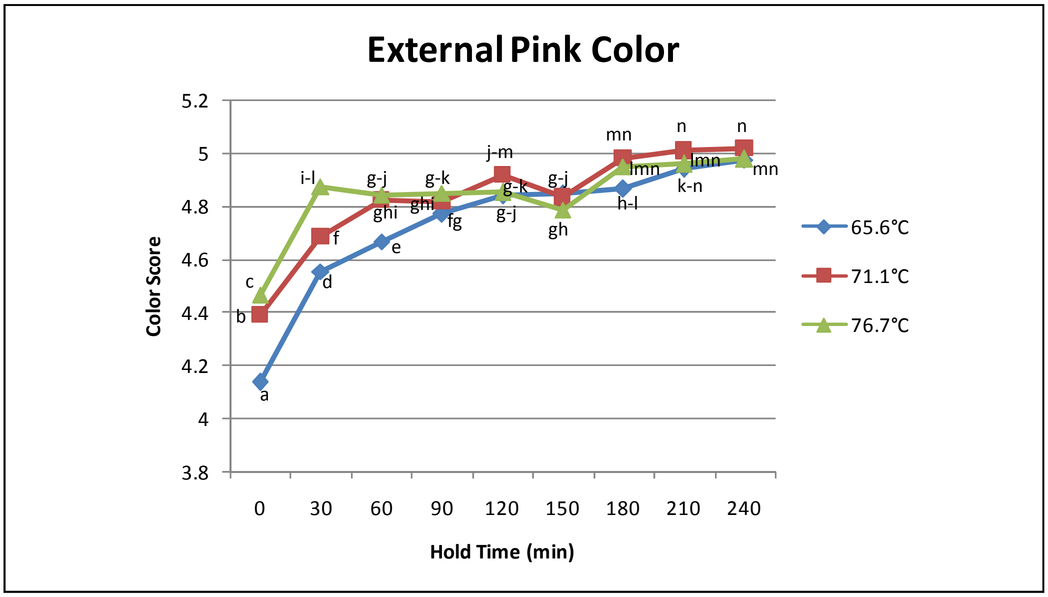

Figure 35. Least squares means for internal cook temperature and holding time interaction for external pink color[o] (P<0.0001[p]).

[a-n]Mean values followed by the same letter are not significantly different (P>0.05).
[o]External Pink Color: 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink.
[p]P-value from analysis of variance tables.

temperature. At 65.6°C, the highest a* and b* color space values were measured at 0 min; 71.1°C and 76.7°C cooked patties were similar at 0 min. At 240 min, 71.1°C cooked patties had the lowest a* and b* color space values and 65.6°C and 76.7°C cooked patties were similar. Patties cooked to 65.6°C were pinker externally, had lower scores, than the patties cooked to 71.1°C and 76.7°C at 0-60 min of holding. Subsequent holding of all patties produced relatively similar pinkness scores which decreased with increased hold times.

Lastly, there were significant (P<0.05) holding method and holding time interactions for external CIE L*, a*, and b* color space values (Figure 36) and for external pink color (Figure 37). Patties decreased in external L*, a*, and b* color space values over hold time in both holding methods. The L* and b* color space values of moist patties were much higher by 60 min of hold time, showing lighter and yellower patties. Color values of moist held patties did not drop swiftly as seen in dry holding. The a* color space values were lower in patties held with moisture until 120 min. At 180 min, dry held patties were less red, had lower a*, than the moist held patties. External pink color was reduced as hold time increased for both holding methods. Patties should have started with equal values from both cooking methods, as equal numbers were placed in the two holding methods. The external pinkness scores, with the exception of 150 min, were similar in patties held 90 to 240 min. The changes in the a* color space values followed similar trends as external pink scores.

Holding of ground beef patties in a both moist and dry environments provided patties that had higher doneness in appearance both internally and externally. The

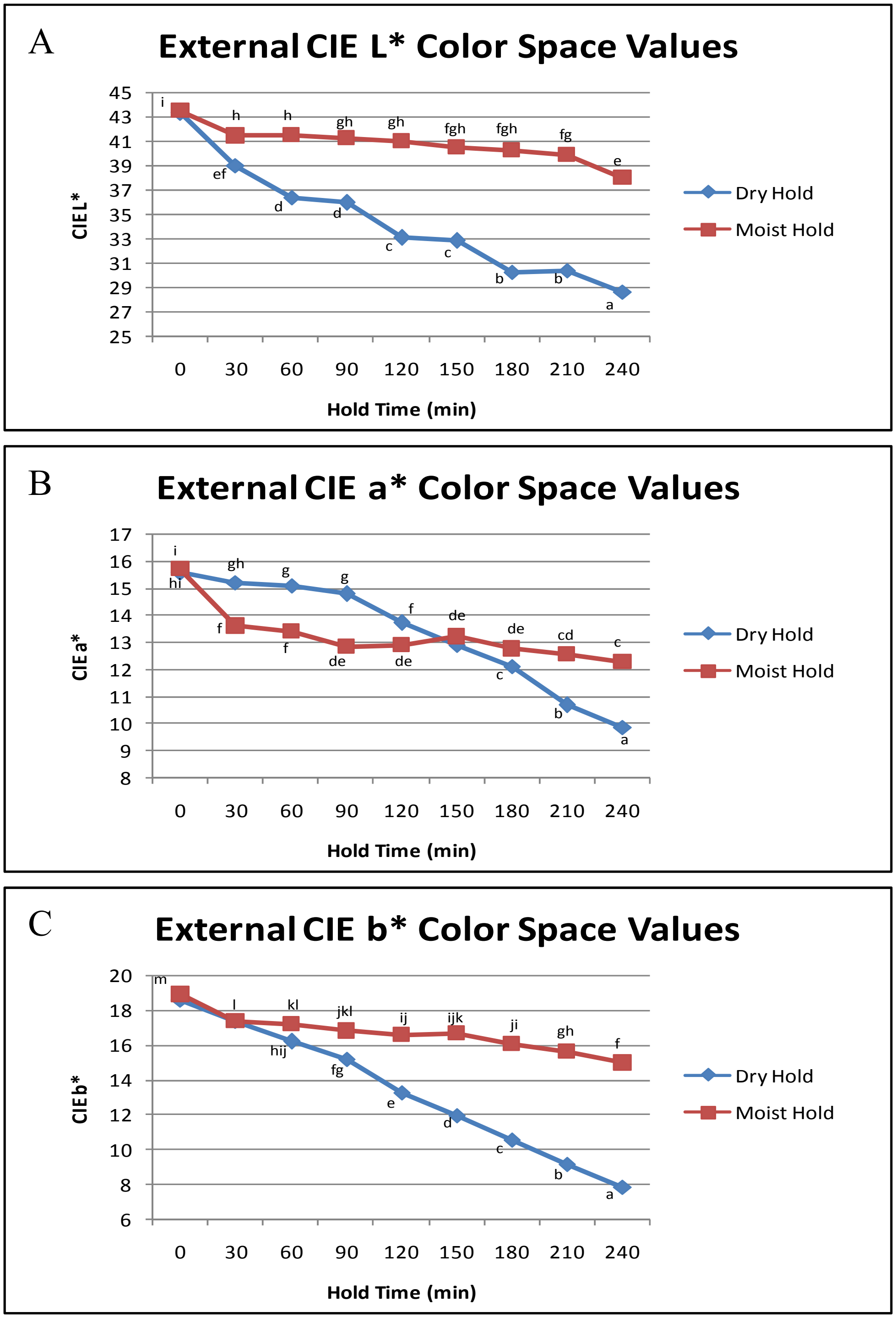

Figure 36. Least squares means for holding method and holding time interactions for external CIE (A) L* (P<0.0001[n]), (B) a* (P<0.0001[n]), and (C) b* (P<0.0001[n]) color space values.

[a-m]Mean values followed by the same letter are not significantly different ($P>0.05$).
[n]P-value from analysis of variance tables.

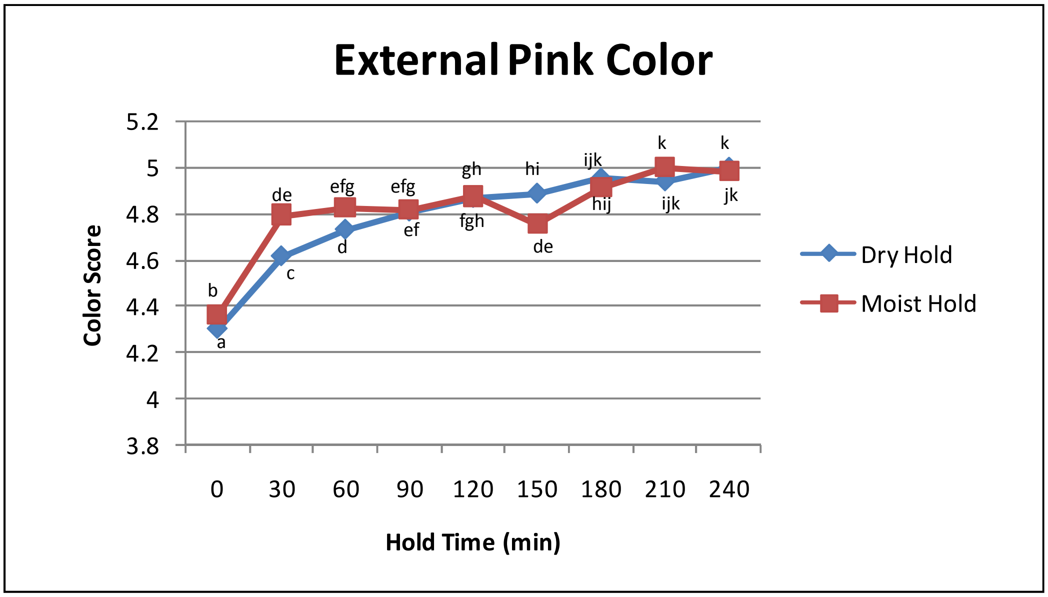

Figure 37. Least squares means for holding method and holding time interaction for external pink color[l] (P<0.0001[m]).

[a-k]Mean values followed by the same letter are not significantly different (P>*0.05*).
[l]External Pink Color: 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink.
[m]P-value from analysis of variance tables.

internal color changes were most evident after 120 min of holding. Color change was the most pronounced externally in ground beef patties that were dry held for long periods of time.

Treatments

Non-meat ingredients, hydrocolloids (xanthan gum and konjac flour) and acetic acid, were introduced to minimize the differences due to meat type effects of pH and myoglobin concentration. With the addition of treatments, raw patty pH and cook yield decreased ($P<0.0001$) (Table 5). Patties containing AA had the lowest cook yield. The addition of either XG or KF with AA, while not changing pH, improved cook yield in ground beef patties. As the control patties did not have added water or acetic acid, higher cook yields were expected. Hydrocolloids such as KF and XG have been shown to improve WHC and cook yields in meat products (Foegeding and Ramsey 1986; Hsia and others 1992; Chin and others 1998); however use of XG/AA improved cook yield where KF/AA and AA patties had similar cook yields to that of control patties. A cook yield interaction was significant ($P<0.05$) for meat type and treatment (Figure 38). Within meat type, treatment effects for cook yield followed similar trends as discussed for main effects, except the magnitude of these effects were influenced by meat type. Ground beef patties from high pH meats were expected to present with the highest cook yields because the high pH binds water more tightly to the proteins (Seideman and others 1984). Additionally, the use of acetic acid in the patties was expected to reduce the cook yield. The combination of the acetic acid and hydrocolloids was hypothesized

Table 5. Least squares means for raw pH and cook yield of ground beef patties as affected by treatment.

Effect	pH	Cook Yield (%)[a]
RMSE[b]	0.15	5.43
Treatment[c]	<0.0001	<0.0001
Control	6.03[e]	75.42[f]
0.5% Acetic Acid	5.83[d]	68.81[d]
0.25% Xanthan Gum/ 0.5% Acetic Acid	5.88[d]	71.07[e]
0.125% Konjac Flour/ 0.5% Acetic Acid	5.81[d]	69.43[d]

[a]Cook yield = (cook weight/raw weight) × 100.
[b]Root mean square error from analysis of variance tables.
[c]*P*-value from analysis of variance tables.
[def]Mean values within a column and followed by the same letter are not significantly different ($P>0.05$).

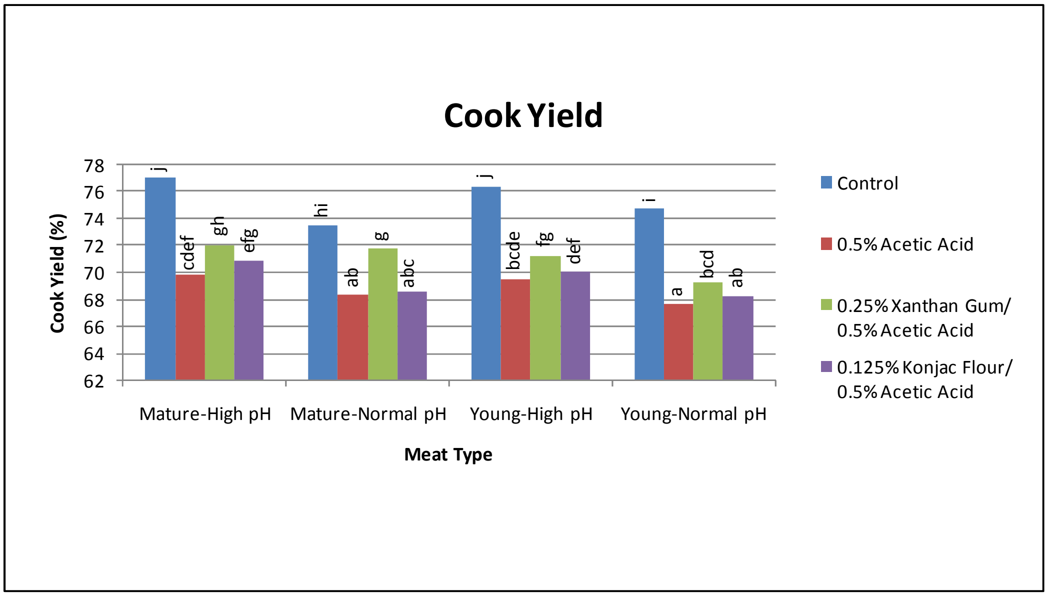

Figure 38. Least squares means for meat type and treatment interaction for cook yield[k] (*P*=0.0399[l]).

[a-j]Mean values followed by the same letter are not significantly different (*P>0.05*).
[k]Cook yield = (cook weight/raw weight) × 100.
[l]*P*-value from analysis of variance tables.

to retain yield of control ground beef patties while having the benefit of a lower pH. For all meat types, control patties had the highest cook yields. Control patty cook yield was lowest for MN patties. The addition of AA lowered cook yield, regardless of meat type and when XG/AA was used, cook yields increased across meat types. The addition of KF/AA did not improve cook yield; however, in higher pH patties, MH and YH, slightly higher cook yield were reported for AA and KF/AA treated patties when compared to the same patties from MN and YN meat types. The higher initial pH of the meat in the MH and YH meat sources most likely contributed to the higher cook yield for these treatments.

An interaction was significant ($P<0.05$) in cook yield for cooking method and treatment (Figure 39). Control patty cook yield was not affected by cook method. As previous reported, XG/AA treated patties had higher cook yields than AA and KF/AA treated patties. Within treated patties, patties cooked using the moist cooking method had lower cook yields than treated patties cooked using dry cooking method. This is probably indicative of the moist cooked patties having a longer cook time than the dry cooked patties, even though it was expected that the dry cooking method would cause surface dehydration thus lower cook yields.

Internal cooked color of patties was affected by treatment (Table 6). Control and treated patties differed in internal color attributes and myoglobin denaturation. The internal CIE L* color space values did not differ with use of treatment (P=0.0591), however CIE a* and b* color space values did vary. Control patties had the highest a* color space values followed by AA and KF/AA containing patties then patties with

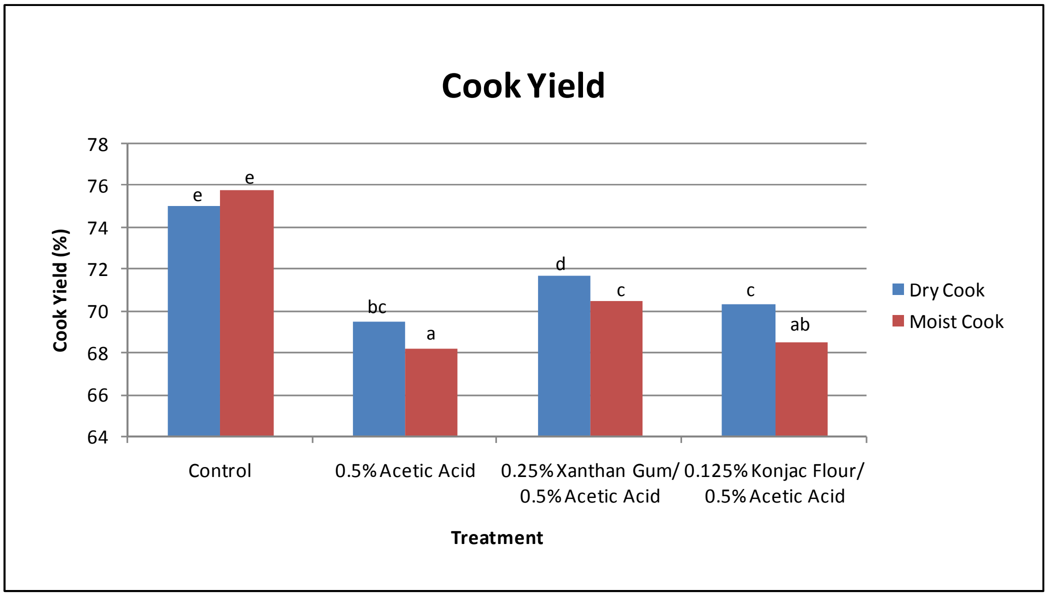

Figure 39. Least squares means for treatment and cooking method interaction for cook yield[f] (P=0.0025[g]).

[a-e]Mean values followed by the same letter are not significantly different ($P>0.05$).
[f]Cook yield = (cook weight/raw weight) × 100.
[g]P-value from analysis of variance tables.

Table 6. Least squares means for internal color attributes and denatured myoglobin of cooked ground beef patties as affected by treatment.

Effect	CIE Color Space Values			Internal	Myoglobin,
	L*	a*	b*	Doneness[a]	Denatured (%)[b]
RMSE[c]	6.39	3.56	2.09	0.60	15.17
Treatment[d]	0.0591	<0.0001	<0.0001	<0.0001	<0.0001
Control	46.81[e]	17.20[g]	17.21[f]	3.28[e]	65.16[e]
0.5% Acetic Acid	47.03[ef]	14.94[e]	16.65[e]	3.71[fg]	71.96[g]
0.25% Xanthan Gum/ 0.5% Acetic Acid	47.88[f]	15.86[f]	17.06[f]	3.64[f]	68.34[f]
0.125% Konjac Flour/ 0.5% Acetic Acid	46.90[e]	15.04[e]	16.58[e]	3.77[g]	72.33[g]

[a]Internal Degree of Doneness: 1 = raw red center, pink border, tan edge (medium rare); 2 = reddish-pink center, pink border, tan edge; 3 = slightly pink center, light brown to tan edge (medium); 4 = tan/brown center and edges, no evidence of pink (well done); 5 = dry, brown throughout (very well done).
[b]Percent of denatured myoglobin = [(total myoglobin – denatured myoglobin)/total myoglobin] × 100.
[c]Root mean square error from analysis of variance tables.
[d]*P*-value from analysis of variance tables.
[efg]Mean values within a column and followed by the same letter are not significantly different (*P>0.05*).

XG/AA were the most red (*P*<0.0001). The CIE b* color space values were highest for control and XG/AA patties; KF/AA and AA patties had the lowest b* color space values (*P*<0.0001). Internal degree of doneness scores were highest in the KF/AA containing patties, then XG/AA patties, and lastly the control patties had the least done appearance (*P*<0.0001). Patties with the AA treatment did not vary from the KF/AA or the XG/AA treatments. Myoglobin also followed a similar trend with the AA and KF/AA had the greatest percentage of denatured myoglobin and the least denatured myoglobin percentage was observed in the control patties (*P*<0.0001).

The addition of AA increased L* color space values and the percentage of myoglobin denaturation. Acid addition was used in high pH patties to determine if higher pH meat could be treated to respond similarly to normal pH meat in cooking. Acetic acid-addition has been shown to effectively reduce muscle pH (Rao and Gault 1990), however, no studies have reported the effect of acetic acid on myoglobin denaturation or on the color attributes of treated meat. Additionally, AA treated patties were less red and yellow and had higher doneness scores than the control patties. The hydrocolloids, KF and XG, were added in combination with AA to determine if their additions would either mask or deter negative effects influenced by meat type, including color and yield. Patties treated with KF/AA and AA had similar color and myoglobin denaturation values indicating that the addition of KF/AA did not negate the detrimental effects of AA addition to beef patties. However, when XG/AA was added, color and myoglobin values improved or resulted in color similar to control patty values. These results indicate that XG addition offset some of the effects for color and myoglobin denaturation that AA addition resulted in. As XG/AA patties had higher cook yields than AA and KF/AA patties, the improvement in color could have been associated with the ability of XG to the more effectively bind water within the patty during cooking.

Interactions for meat type and treatment were significant (*P*<0.05) for internal CIE a* and b* color space values (Figure 40). Treatments were effective in all meat types at reducing redness compared to control except the MN ground beef patties with XG/AA treatment. Treatment addition decrease a* values in high pH meat, except this effect differed for mature and young beef. When treatments were added to YH beef, patties were less red and did not differ in redness across treatments. For MH beef, AA treated patties had the lowest a* color space values and XG/AA treated patties were more red, although not as red as control patties. These results indicated that XG addition with AA is providing a protective effect to assist in maintaining redness values of cooked patties. This effect was more pronounced in mature beef most likely due to the high myoglobin content when compared to the young beef patties. The MN patties were redder than patties from young beef. When treated, a similar effect was reported, even though the magnitude was not as pronounced. MN patties treated with AA or KF/AA were less red than control patties and the addition of XG/AA improved redness values to those of controls. For YN patties, treatment effects of redness values decreased, but differences between treatments in redness were minimal. The overall goal of this

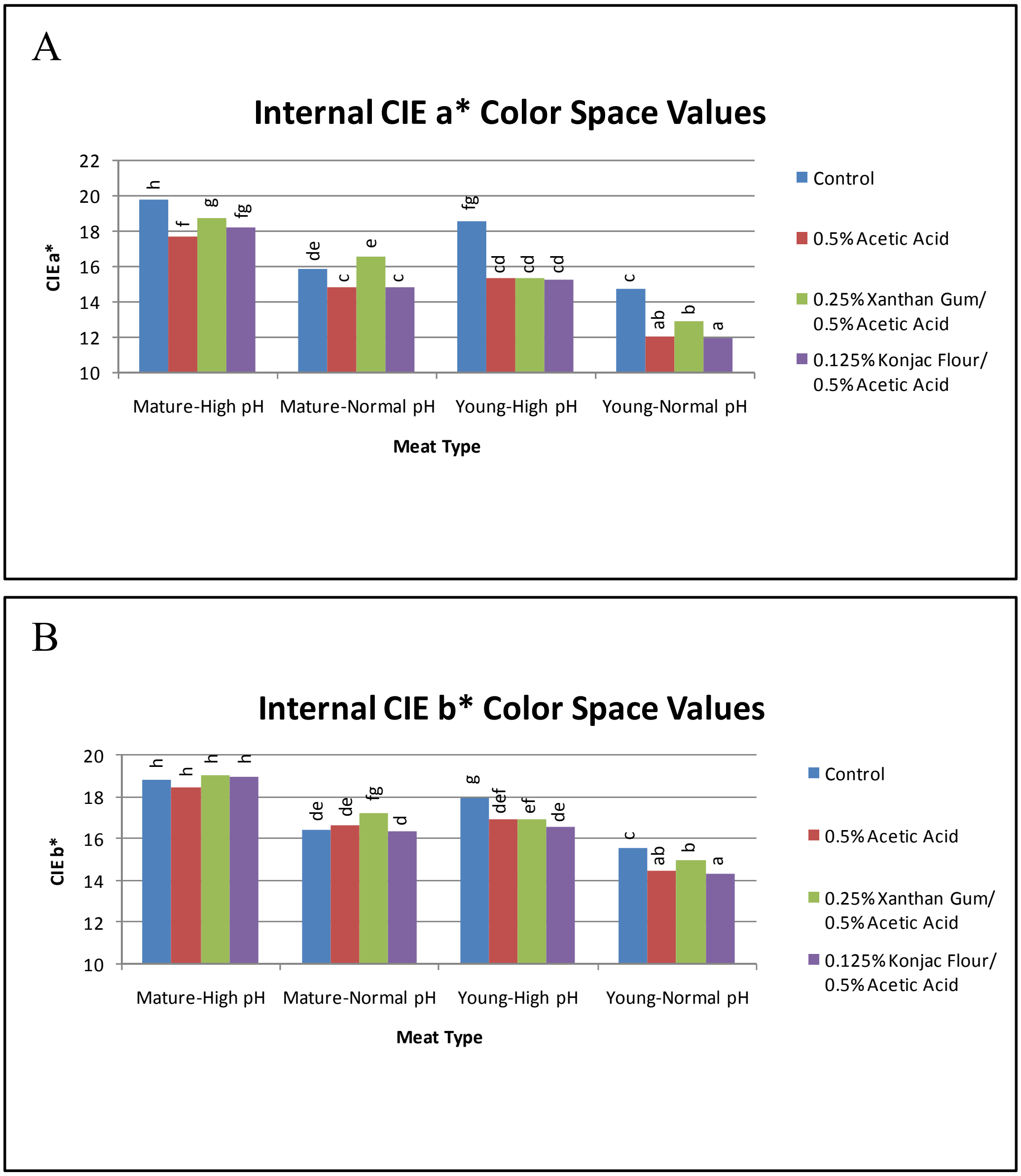

Figure 40. Least squares means for meat type and treatment interactions for internal CIE (A) a* (P<0.0001[i]) and (B) b* (P<0.0001[i]) color space values.

[a-h]Mean values followed by the same letter are not significantly different (P>0.05).
[i]P-value from analysis of variance tables.

research was to ad ingredients so that patties had similar color as YN control patties. Internal a* color space values for MN, AA and KF/AA and YH treated patties were the same as YN control patties indicated that these treatments may effectively improve color of patties from YH and MN meat sources. However, yellowness values were not as strongly effected by treatment. The level of AA, KF and or XG may have not been sufficient to effect myoglobin denaturation of MH beef patties that would have the highest myoglobin content at a high pH.

When treatments were applied, a cooking method interaction was significant (P<0.05) for internal CIE a* color space values (Figure 41). The addition of AA resulted in lower a* color space values, regardless of cooking method. When KF with AA was added, redness values decreased except KF/AA patties cooked using the dry method which resulted in patties that were redder. The addition of XG with AA resulted in lower a* color space values of moist cooked patties were lower than values for dry cooked patties. As XG/AA patties had higher cook yield indicating higher water holding capacity during cooking. This effect most likely assisted in limiting the decrease in redness with cooking, especially when using dry cooking methods.

Color values associated with the external appearance of the patties also varied due to treatment differences (Table 7). The CIE L*, a*, and b* color space values responded similarly when treatments were applied (P<0.0001). Generally, the XG/AA treatment had the highest CIE color space values, followed by KF/AA, then AA, and with the lowest values in the control patties. No differences were found in the external

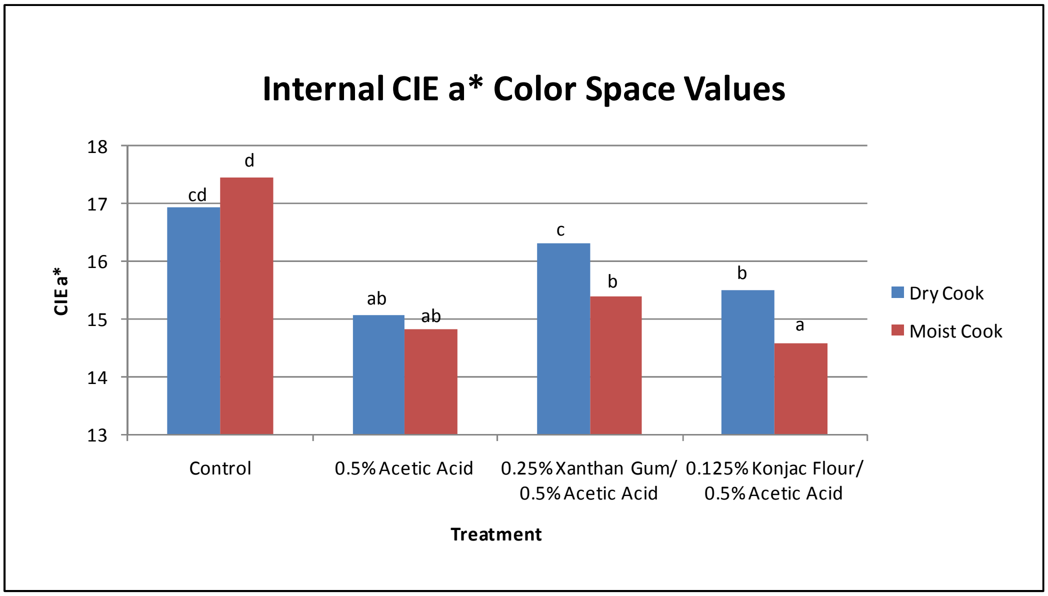

Figure 41. Least squares means for treatment and cooking method interaction for internal CIE a* color space values (*P*=0.0073[e]).

[a-d]Mean values followed by the same letter are not significantly different (*P>0.05*).
[e]*P*-value from analysis of variance tables.

Table 7. Least squares means for external color attributes of cooked ground beef patties as affected by treatment.

Effect	CIE Color Space Values L*	a*	b*	External Pink Color[a]
RMSE[b]	7.91	2.56	3.34	0.33
Treatment[c]	<0.0001	<0.0001	<0.0001	0.2254
Control	35.45[d]	12.51[d]	13.37[d]	4.80
0.5% Acetic Acid	37.96[e]	13.24[e]	15.13[e]	4.81
0.25% Xanthan Gum/ 0.5% Acetic Acid	38.70[f]	13.76[f]	16.00[g]	4.78
0.125% Konjac Flour/ 0.5% Acetic Acid	38.27[ef]	13.60[f]	15.55[f]	4.81

[a]External Pink Color: 1 = dark red to purple, uncooked appearance; 2 = bright red; 3 = very pink; 4 = slightly pink; 5 = tan, no evidence of pink.
[b]Root mean square error from analysis of variance tables.
[c]*P*-value from analysis of variance tables.
[defg]Mean values within a column and followed by the same letter are not significantly different (*P>0.05*).

pink color of the patties, indicating the differences found above may not be evident to humans.

External color interactions were significant (*P*<0.05) for CIE L*, a* and b* color space values for treatment and meat type (Figure 42). Ground beef patties were lighter with the addition of treatments with MN, YH, and YN meat types as well as MH ground beef patties with XG/AA compared to the control patties. Patties with AA or KF/AA did not differ compared to control when made with MH meat. An increase in redness was observed in the mature meat sources with treatments compared with controls. This was not an expected result and is opposite of what was observed in the interior of the patties. Though not what was expected in this study, others have reported an increase in a* and b* of raw beef the surface spraying of an acetic and lactic acid spray (Mikel and others 1996). Treatment did not affect the YN meat patties except for XG/AA which had a slight increase in redness. Ground beef patties made from YH meat had an increase in a* color space values with treatments compared to the control. Treatment additions increased patty yellowness compared to control in all meat types. The XG/AA treatment produced patties that were more yellow in the mature meats compared to other treatments. Little to no difference was observed in treatments in young meat patties which were generally more yellow than the mature meat patties.

External CIE a* and b* color space values had a significant (*P*<0.05) interaction for cooking method and treatment (Figure 43). The a* color space values did not differ between dry and moist cooking for the AA treatment. Patties with hydrocolloids were less red in the moist cooking compared to the dry cooking method. External redness

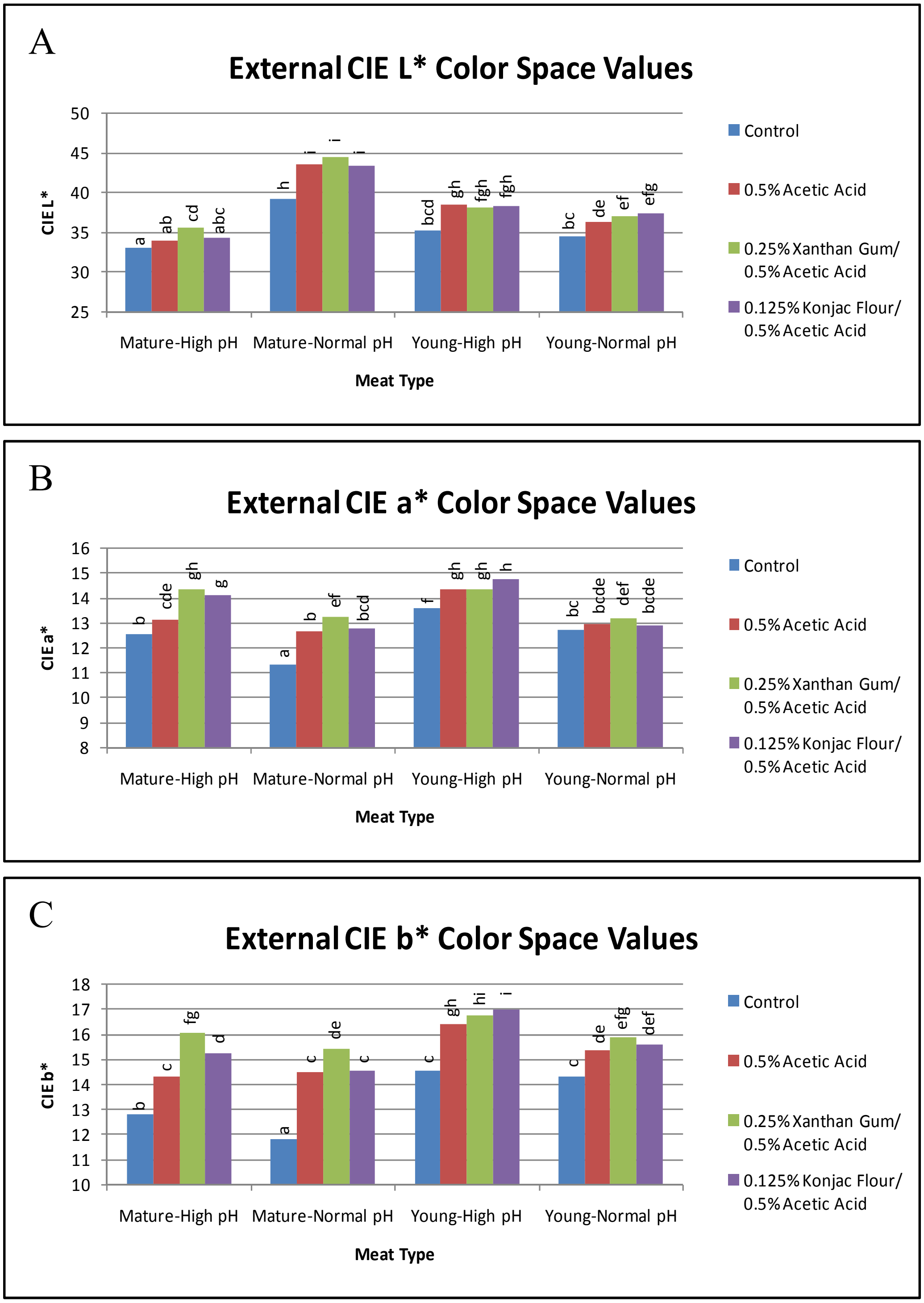

Figure 42. Least squares means for meat type and treatment interactions for external CIE (A) L* (P=0.0048[j]), (B) a*(P<0.0001[j]), and (C) b* (P<0.0001[j]) color space values.

[a-i]Mean values followed by the same letter are not significantly different ($P>0.05$).
[j]P-value from analysis of variance tables.

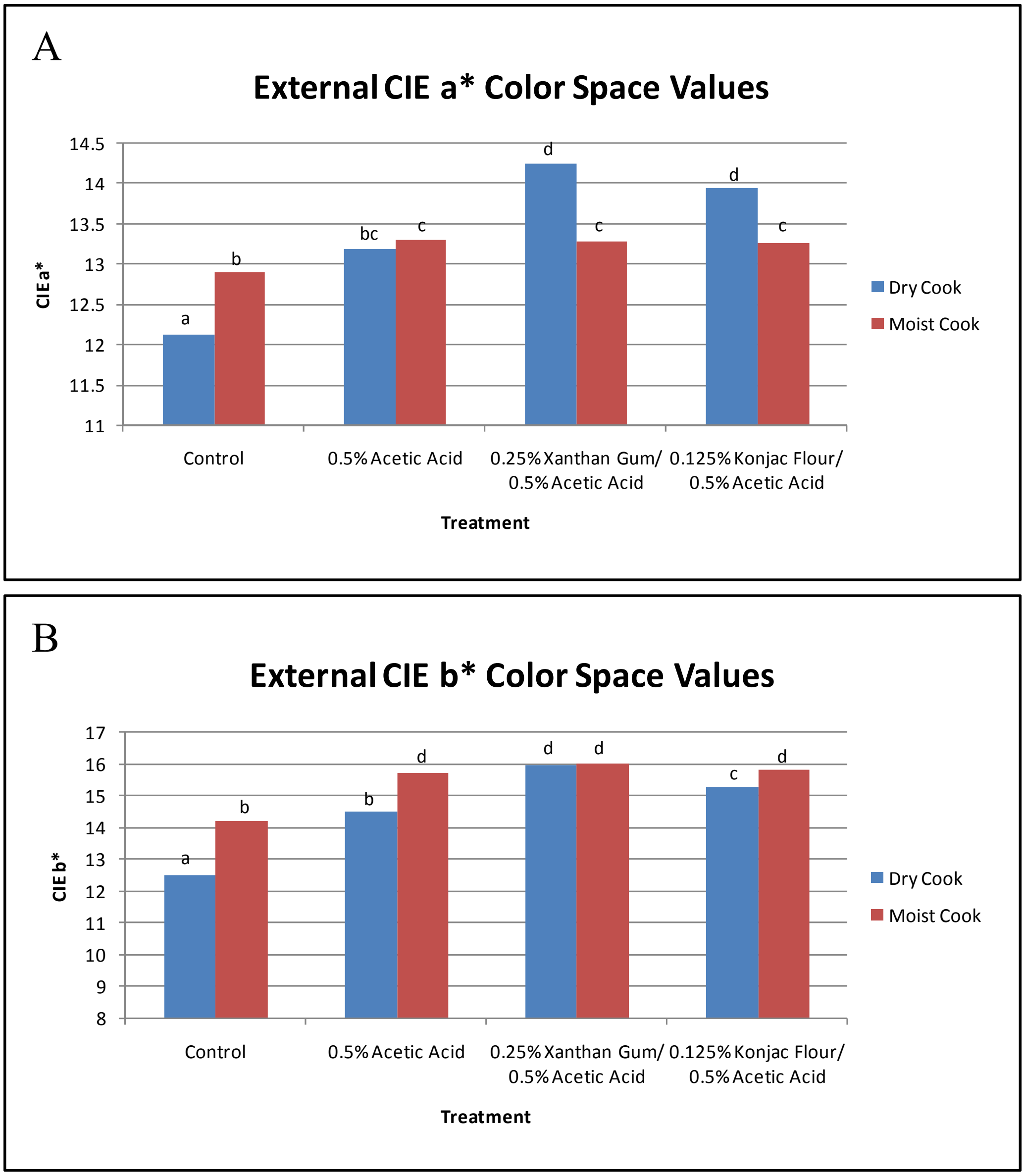

Figure 43. Least squares means for treatment and cooking method interactions for external CIE (A) a* (P<0.0001[f]) and (B) b* (P<0.0001[f]) color space values.

[a-e]Mean values followed by the same letter are not significantly different (P>0.05).
[f]P-value from analysis of variance tables.

(a*) was the highest for dry cooked patties with hydrocolloids and lowest in the dry cooked, control patties. The b* color space values were the highest in the dry and moist cooked-XG/AA treated, moist cooked-AA treated, and the moist cooked-KF/AA treated patties. The control, AA, and KF/AA treatments produced patties that were more yellow with moist cooking than in dry cooking.

External CIE a* and b* color space values significantly (P<0.05) varied in their response to treatment for the different internal cook temperature (Figure 44). The control patties had the lowest a* and b* color space values at all temperatures compared to all other treatments. The XG/AA and KF/AA treatments were similar in redness (a*) and yellowness (b*). These two treatments presented with the highest values at 65.6°C then decreased with the temperature of 71.1°C. The KF/AA treatment did not change when internal cook temperature increased to 76.7°C. The XG/AA treatment had increased in the redness and yellowness at 76.7°C compared to 71.1°C. The AA treated patties had lower values than XG/AA at 65.6°C then responded similarly when they lowered at 71.1°C and increased at 76.7°C. The a* values for the AA treated patties were not different in the 71.1°C and 76.7°C cook temperature groups.

Interactions were significant (P<0.05) for CIE a* color space values for treatment and holding method (Figure 45) and treatment and holding time (Figure 46). The a* color space values did not differ due to holding method within treatment groups. One exception was in the control, where higher a* color space values were observed in moist holding compared to dry holding. The a* color space values were higher for patties with XG/AA and KF/AA treatments and lowest for the control patties. The a*

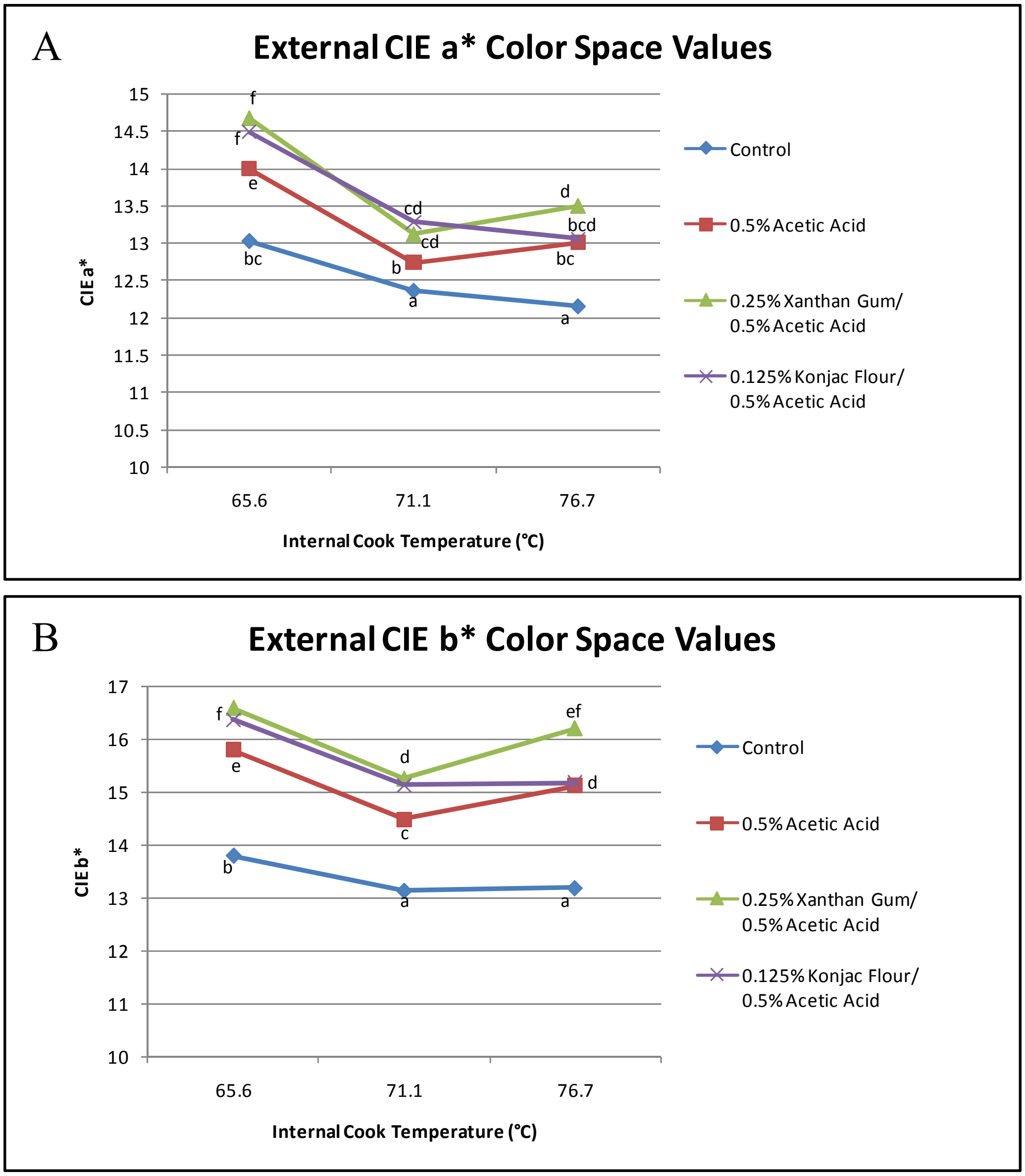

Figure 44. Least squares means for treatment and internal cook temperature interactions for external CIE (A) a* (P=0.0117[g]) and (B) b* (P=0.0327[g]) color space values.

[a-f]Mean values followed by the same letter are not significantly different ($P>0.05$).
[g]P-value from analysis of variance tables.

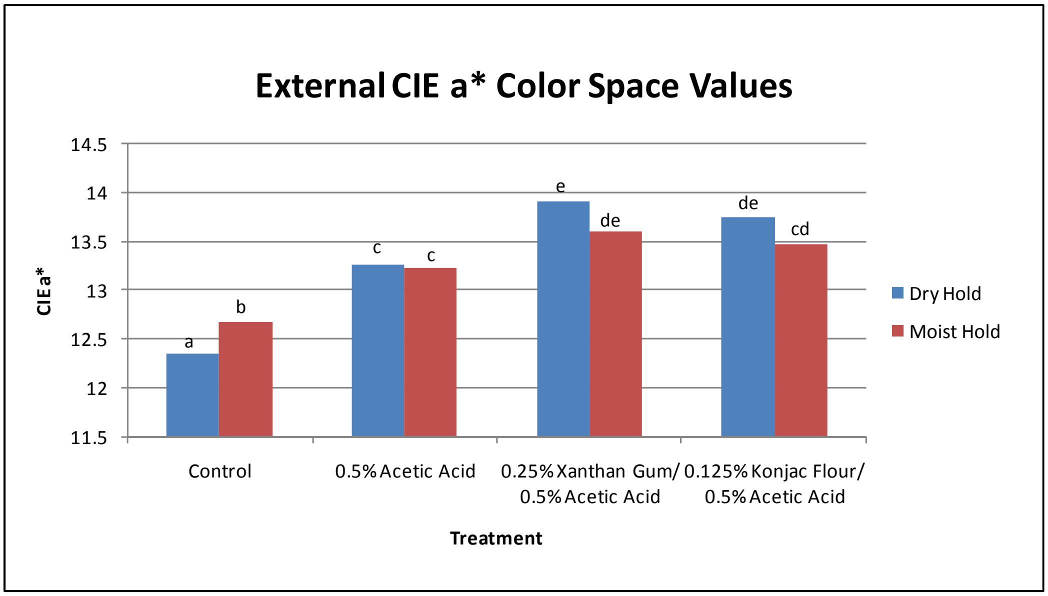

Figure 45. Least squares means for treatment and holding method interaction for external CIE a* color space values (P=0.041[f]).

[a-e]Mean values followed by the same letter are not significantly different ($P>0.05$).
[f]P-value from analysis of variance tables.

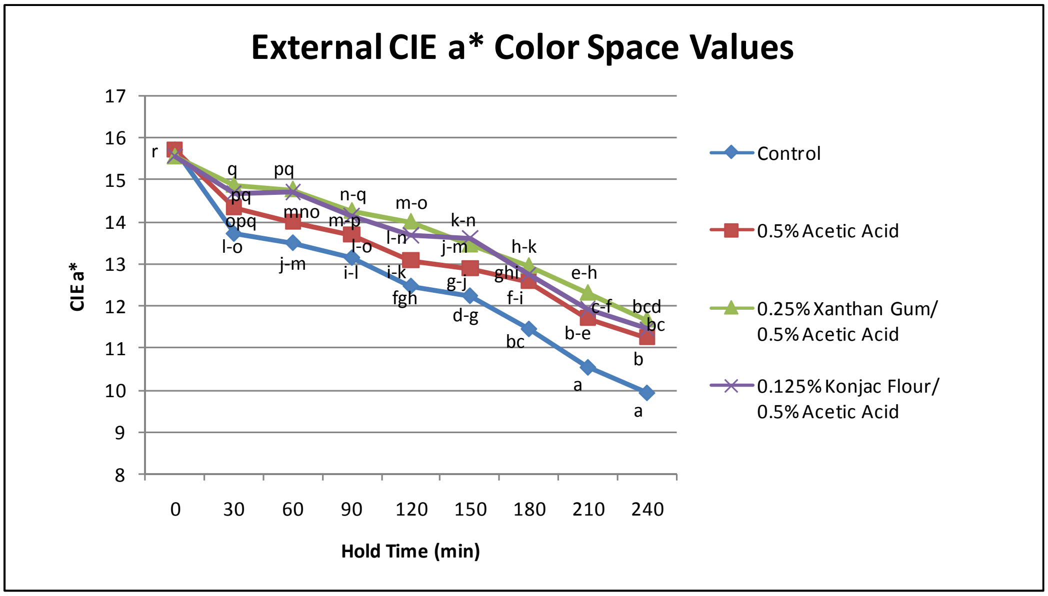

Figure 46. Least squares means for treatment and holding time interaction for external CIE a* color space values (P=0.0344[v]).

[a-u]Mean values followed by the same letter are not significantly different ($P>0.05$).
[v]P-value from analysis of variance tables.

color space values did not differ at 0 min between treatments. The a* color space values decreased over holding time. Patties with treatments still had more redness and yellowness than the control patties that were less red than treatments at all times over 0 min. Color in patties with the acetic acid and hydrocolloids was protected. The acetic acid could prevent the oxidation of the heme iron in myoglobin keeping it in ferrohemochrome state which is a dull red color versus the ferrihemochrome state which is brown in color (King and Whyte 2006). However, this was only evident on the surface of the patties as color of the interior of the patties reduced with increases in holding time.

When acid is added there is a reduction of pH which results in the system being closer to the proteins' pI. As proteins approach their pIs the net charge on the protein is reduced and there is a loss of water as proteins favor interaction with other proteins over water. Therefore, it would be expected that with the addition of acid there would be a decrease in cook yield in those hamburger patties and there would be a greater about of myoglobin denaturation or a more done appearance. Because the addition of acetic acid was expected to increase the water loss, the hydrocolloids were added. Hydrocolloids may be able to fill the interstitial space, reducing the loss of water due to the reduction in pH by acid addition. By filling these spaces, the hydrocolloids were expected to improved quality in two ways: by improving the cook yield compared to acid addition alone and by holding the acid close to the proteins to improve the acid's effectiveness to reduce the pH and improve cook color. The hypothesis regarding the cook yield appears to be correct in that the hydrocolloids retain cook yield even with acid introduction.

The color of the ground beef patties varied with treatment incorporation. The treatments, primarily KF/AA and AA, were able to reduced a* color space values internally in YH and MN to that close to control YN patties. These two meat types, YH and MN, only had to overcome either high pH or high myoglobin concentrations. The MH patties were not influenced by the treatments, probably because they had both high pH and high concentrations of myoglobin.

CHAPTER V

CONCLUSIONS

This study was designed to evaluate the effect of common foodservice style cooking and holding methods. Meat type differences were chosen to induce variation in myoglobin and pH which is routinely found in ground beef applications. Treatments were incorporated in the ground beef as an attempt to reduce the influences the meat types imparted by cooking and holding methods, internal cook temperature, and holding time. Of all the effects studied, internal color values were more effective at showing the effects of meat types, internal cook temperatures, holding methods and times, treatments than the external color values. Cooking method effects were best understood by the external color values.

The YN patties had the most done appearance internally and the highest denatured myoglobin percentage. The MH patties had the highest internal a* color space values and lowest degree of doneness scores and low myoglobin denaturation. The YN patties responded normally to cooking to the different internal temperatures. The YH, MN, and MH patties had increased doneness to 71.1°C and plateaued from 71.1°C to 76.7°C. The pink/red color of the ground beef patties was returned during holding in the moist held patties and was most evident in dry cook/moist held patties. Patties from MH meat was not affected as much by treatments as the other meat types. The use of AA, XG/AA, and KF/AA in patties made from YH and MN can effectively reduce the redness and increase myoglobin denaturation to that comparable to the control YN beef patties. These ingredients could be viable options to reduce the variation that pH or myoglobin content imparts on ground beef patty cooked color, but as seen in the MH meat, treatment additions were not effective to overcome both pH and high myoglobin content.

Further evaluation of these types of ingredients in ground beef patties should be performed. Varying the types of organic acids used with hydrocolloids would be beneficial to see if the ground beef patties respond differently and to determine if one is more effective at reducing the pH and improving cooked color. Varying the levels of the acid and hydrocolloids included would have provided greater knowledge regarding the effectiveness in young and mature meat. Sensory testing either with trained descriptive panelists should be conducted to give an understanding of the differences that are present in these ground beef patties compared to those not containing any acetic acid or hydrocolloids. Consumer evaluation should be utilized to determine the acceptability of the treatments on the flavor of ground beef patties. After including the treatments, it would prudent to determine if a rest time from mixing to cooking increases the effectiveness of the treatments on reducing the pH and/or on improving the cooked color.

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APPENDIX A

AOV TABLES

Table A-1. ANOVA table[a] for raw meat pH.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	10.81	-
Trt	3	86	10.58	<0.0001
Age*pH	3	86	34.26	<0.0001
Time	1	86	0.16	0.6904

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-2. ANOVA table[a] for cook time.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	0.00	-
Age*pH	3	134	4.68	0.0038
Cook	1	134	83.68	<0.0001
Temp	2	134	13.24	<0.0001

[a]Type 3 Tests of Fixed Effects.
[b]Rep = replication, random effect; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature.

Table A-3. ANOVA table[a] for cook yield.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	40.09	-
Trt	3	1630	130.12	<0.0001
Age*pH	3	1630	19.03	<0.0001
Cook	1	1630	11.53	0.0007
Temp	2	1630	98.40	<0.0001
Hold	1	1630	673.64	<0.0001
Time	2	1630	581.37	<0.0001
Trt*Age*pH	9	1630	1.96	0.0399
Trt*Cook	3	1630	4.80	0.0025
Age*pH*Temp	6	1630	5.10	<0.0001
Age*pH*Time	6	1630	4.48	0.0002
Temp*Time	4	1630	2.42	0.0470
Hold*Time	2	1630	211.67	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-4. ANOVA table[a] for internal L* color space values.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	318.54	-
Trt	3	1670	2.48	0.0591
Age*pH	3	1670	185.67	<0.0001
Cook	1	1670	0.34	0.5617
Temp	2	1670	3.49	0.0308
Hold	1	1670	0.10	0.7461
Time	2	1670	9.33	<0.0001
Age*pH*Time	6	1670	7.61	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-5. ANOVA table[a] for internal a* color space values.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	0.00	-
Trt	3	1620	36.36	<0.0001
Age*pH	3	1620	184.42	<0.0001
Cook	1	1620	5.13	0.0236
Temp	2	1620	86.31	<0.0001
Hold	1	1620	86.51	<0.0001
Time	2	1620	111.28	<0.0001
Trt*Age*pH	9	1620	3.76	0.0001
Trt*Cook	3	1620	4.02	0.0073
Age*pH*Cook	3	1620	3.31	0.0195
Age*pH*Temp	6	1620	2.60	0.0165
Age*pH*Hold	3	1620	5.68	0.0007
Age*pH*Time	6	1620	3.05	0.0057
Cook*Temp	2	1620	12.60	<0.0001
Hold*Time	2	1620	37.81	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-6. ANOVA table[a] for internal b* color space values.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	129.19	-
Trt	3	1622	9.16	<0.0001
Age*pH	3	1622	259.68	<0.0001
Cook	1	1622	3.51	0.0612
Temp	2	1622	34.67	<0.0001
Hold	1	1622	45.85	<0.0001
Time	2	1622	63.42	<0.0001
Trt*Age*pH	9	1622	3.73	0.0001
Age*pH*Cook	3	1622	7.89	<0.0001
Age*pH*Hold	3	1622	2.60	0.0510
Age*pH*Time	6	1622	2.07	0.0544
Cook*Temp	2	1622	6.69	0.0013
Hold*Time	2	1622	20.04	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-7. ANOVA table[a] for internal chroma values.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	0.00	-
Trt	3	1621	25.04	<0.0001
Age*pH	3	1621	240.16	<0.0001
Cook	1	1621	4.42	0.0357
Temp	2	1621	66.44	<0.0001
Hold	1	1621	67.55	<0.0001
Time	2	1621	97.43	<0.0001
Trt*Age*pH	9	1621	4.07	<0.0001
Age*pH*Cook	3	1621	6.15	0.0004
Age*pH*Hold	3	1621	3.81	0.0097
Age*pH*Time	6	1621	2.85	0.0092
Cook*Temp	2	1621	10.84	<0.0001
Cook*Hold	1	1621	4.11	0.0428
Hold*Time	2	1621	32.17	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-8. ANOVA table[a] for internal degree of doneness scores.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	51.71	-
Trt	3	1344	47.69	<0.0001
Age*pH	3	1344	99.81	<0.0001
Cook	1	1344	0.87	0.3514
Temp	2	1344	108.44	<0.0001
Hold	1	1344	126.27	<0.0001
Time	2	1344	154.83	<0.0001
Age*pH*Temp	6	1344	2.96	0.0071
Age*pH*Time	6	1344	13.74	<0.0001
Cook*Temp	2	1344	11.57	<0.0001
Cook*Hold	1	1344	4.64	0.0315
Temp*Time	4	1344	4.77	0.0008
Hold*Time	2	1344	33.40	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-9. ANOVA table[a] for denatured myoglobin.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	33.11	-
Trt	3	1096	14.14	<0.0001
Age*pH	3	1096	134.38	<0.0001
Cook	1	1096	0.07	0.7930
Temp	2	1096	76.36	<0.0001
Hold	1	1096	1.07	0.3018
Time	1	1096	17.38	<0.0001
Age*pH*Cook	3	1096	2.66	0.0471
Age*pH*Temp	6	1096	2.32	0.0313

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-10. ANOVA table[a] for external L* color space values.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	134.99	-
Trt	3	4267	37.75	<0.0001
Age*pH	3	4267	222.15	<0.0001
Cook	1	4267	299.67	<0.0001
Temp	2	4267	19.28	<0.0001
Hold	1	4267	684.15	<0.0001
Time	8	4267	77.63	<0.0001
Trt*Age*pH	9	4267	2.64	0.0048
Age*pH*Cook	3	4267	5.76	0.0006
Age*pH*Temp	6	4267	12.31	<0.0001
Age*pH*Hold	3	4267	23.84	<0.0001
Age*pH*Time	24	4267	2.47	<0.0001
Cook*Temp	2	4267	9.66	<0.0001
Cook*Time	8	4267	2.45	0.0121
Hold*Time	8	4267	23.26	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-11. ANOVA table[a] for external a* color space values.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	16.16	-
Trt	3	4108	50.82	<0.0001
Age*pH	3	4108	91.07	<0.0001
Cook	1	4108	5.57	0.0183
Temp	2	4108	92.13	<0.0001
Hold	1	4108	0.78	0.3784
Time	8	4108	160.32	<0.0001
Trt*Age*pH	9	4108	6.02	<0.0001
Trt*Cook	3	4108	25.90	<0.0001
Trt*Temp	6	4108	2.74	0.0117
Trt*Hold	3	4108	3.54	0.0140
Trt*Time	24	4108	1.59	0.0344
Age*pH*Cook	3	4108	21.85	<0.0001
Age*pH*Temp	6	4108	11.55	<0.0001
Age*pH*Hold	3	4108	20.27	<0.0001
Age*pH*Time	24	4108	6.33	<0.0001
Cook*Temp	2	4108	8.57	0.0002
Cook*Hold	1	4108	106.51	<0.0001
Cook*Time	8	4108	14.37	<0.0001
Temp*Hold	2	4108	11.99	<0.0001
Temp*Time	16	4108	3.26	<0.0001
Hold*Time	8	4108	45.56	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-12. ANOVA table[a] for external b* color space values.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	0.00	-
Trt	3	4153	130.99	<0.0001
Age*pH	3	4153	76.75	<0.0001
Cook	1	4153	75.52	<0.0001
Temp	2	4153	40.49	<0.0001
Hold	1	4153	1022.23	<0.0001
Time	8	4153	264.78	<0.0001
Trt*Age*pH	9	4153	5.47	<0.0001
Trt*Cook	3	4153	12.93	<0.0001
Trt*Temp	6	4153	2.29	0.0327
Age*pH*Cook	3	4153	20.21	<0.0001
Age*pH*Temp	6	4153	19.13	<0.0001
Age*pH*Hold	3	4153	23.15	<0.0001
Age*pH*Time	24	4153	4.75	<0.0001
Cook*Temp	2	4153	7.78	0.0004
Cook*Hold	1	4153	109.99	<0.0001
Cook*Time	8	4153	10.22	<0.0001
Temp*Hold	2	4153	21.80	<0.0001
Temp*Time	16	4153	1.72	0.0371
Hold*Time	8	4153	80.66	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-13. ANOVA table[a] for external chroma values.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	107.53	-
Trt	3	4127	116.66	<0.0001
Age*pH	3	4127	94.04	<0.0001
Cook	1	4127	16.33	<0.0001
Temp	2	4127	73.91	<0.0001
Hold	1	4127	415.60	<0.0001
Time	8	4127	266.66	<0.0001
Trt*Age*pH	9	4127	6.95	<0.0001
Trt*Cook	3	4127	21.37	<0.0001
Trt*Temp	6	4127	3.09	0.0051
Trt*Time	24	4127	1.67	0.0213
Age*pH*Cook	3	4127	24.51	<0.0001
Age*pH*Temp	6	4127	18.15	<0.0001
Age*pH*Hold	3	4127	25.89	<0.0001
Age*pH*Time	24	4127	6.00	<0.0001
Cook*Temp	2	4127	10.51	<0.0001
Cook*Hold	1	4127	134.97	<0.0001
Cook*Time	8	4127	13.86	<0.0001
Temp*Hold	2	4127	20.46	<0.0001
Temp*Time	16	4127	2.65	0.0004
Hold*Time	8	4127	70.75	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

Table A-14. ANOVA table[a] for external pinkness scores.

Effect[b]	Num DF	Den DF	F Value	Pr > F
Rep	2	0	97.96	-
Trt	3	3397	1.45	0.2254
Age*pH	3	3397	20.87	<0.0001
Cook	1	3397	161.50	<0.0001
Temp	2	3397	34.04	<0.0001
Hold	1	3397	3.06	0.0805
Time	8	3397	154.71	<0.0001
Age*pH*Cook	3	3397	6.24	0.0003
Age*pH*Temp	6	3397	2.63	0.0152
Age*pH*Hold	3	3397	12.98	<0.0001
Age*pH*Time	24	3397	11.33	<0.0001
Cook*Temp	2	3397	7.30	0.0007
Cook*Time	8	3397	11.75	<0.0001
Temp*Time	16	3397	6.42	<0.0001
Hold*Time	8	3397	5.69	<0.0001

[a]Type 3 Tests of Fixed Effects
[b]Rep = replication, random effect; Trt = treatment; Age*pH = meat type, main effect, not interaction; Cook = cooking method; Temp = internal cook temperature; Hold = holding method; Time = holding time; "*" = interaction of attributes.

APPENDIX B

CHROMA DATA

Table B-1. Least squares means for chroma of cooked ground beef patties as affected by meat type, treatment, cooking method, internal cook temperature, holding method, and holding time.

Effect	Internal Chroma[a]	External Chroma[a]
RMSE[b]	3.80	3.77
Meat Type[c]	<0.0001	<0.0001
Mature-High pH	26.69[g]	20.02[e]
Mature-Normal pH	22.92[e]	18.96[d]
Young-High pH	23.60[f]	21.70[f]
Young-Normal pH	19.73[d]	20.11[e]
Treatment[c]	<0.0001	<0.0001
Control	24.42[f]	18.46[d]
0.5% Acetic Acid	22.50[d]	20.22[e]
0.25% Xanthan Gum + 0.5% Acetic Acid	23.51[e]	21.28[g]
0.125% Konjac Flour + 0.5% Acetic Acid	22.51[d]	20.83[f]
Cooking Method[c]	0.0357	<0.0001
Dry	23.43[e]	19.96[d]
Moist	23.04[d]	20.43[e]
Internal Cook Temperature, °C[c]	<0.0001	<0.0001
65.6	24.73[e]	21.18[f]
71.1	22.68[d]	19.54[d]
76.7	22.29[d]	19.87[e]
Holding Method[c]	<0.0001	<0.0001
Dry	22.47[d]	19.00[d]
Moist	23.99[e]	21.39[e]

Table B-1. Continued.

Effect	Internal Chroma[a]	External Chroma[a]
Holding Time, min[c]	<0.0001	<0.0001
0	24.26[e]	24.49[l]
30	-	22.68[k]
60	-	22.04[j]
90	-	21.29[i]
120	24.02[e]	20.14[h]
150	-	19.53[g]
180	-	18.35[f]
210	-	17.15[e]
240	21.42[d]	16.10[d]

[a]Chroma = $(a^{*2} + b^{*2})^{1/2}$.
[b]Root mean square error from analysis of variance tables.
[c]*P*-value from analysis of variance tables.
[defghijkl]Mean values within a column and followed by the same letter are not significantly different (*P>0.05*).

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